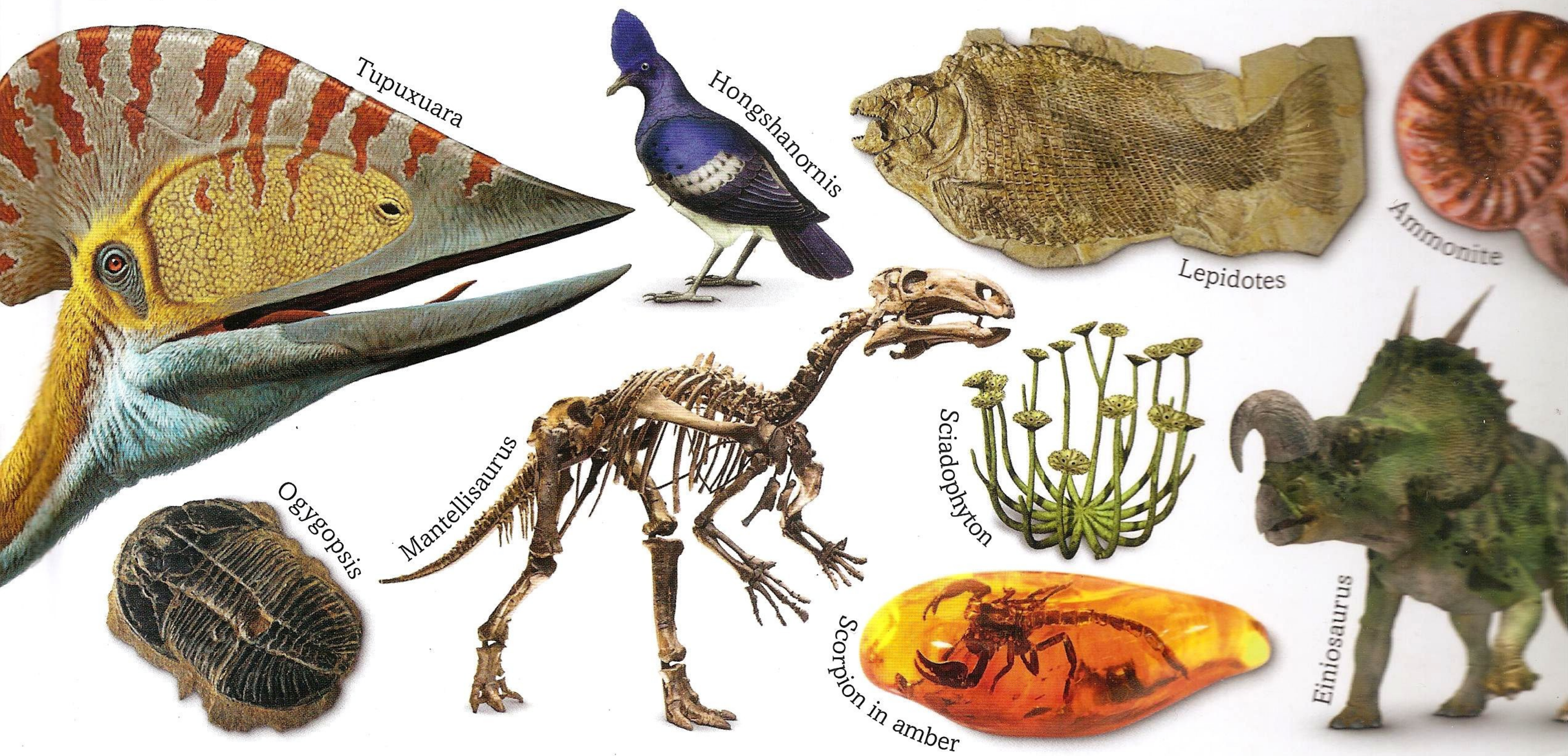
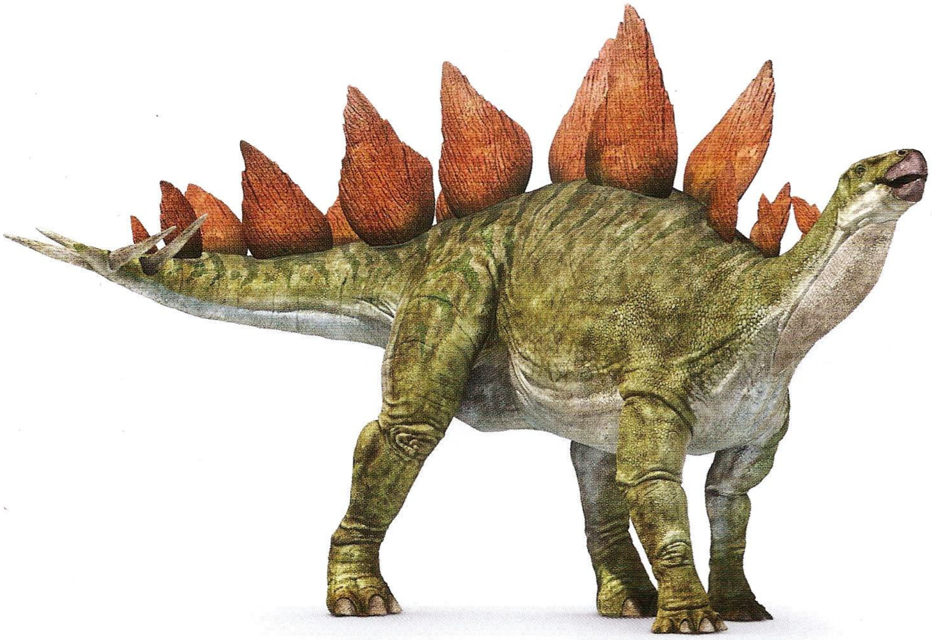
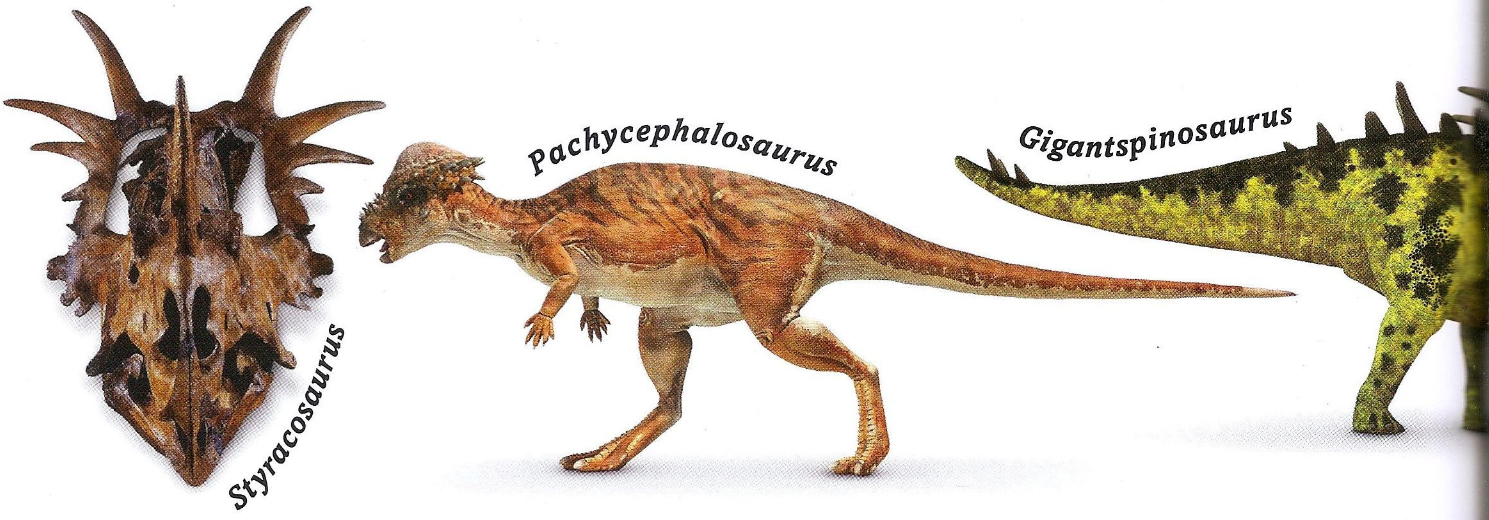
DK SMITHSONIAN



THE DINOSAUR BOOK

THE DINOSAUR BOOK



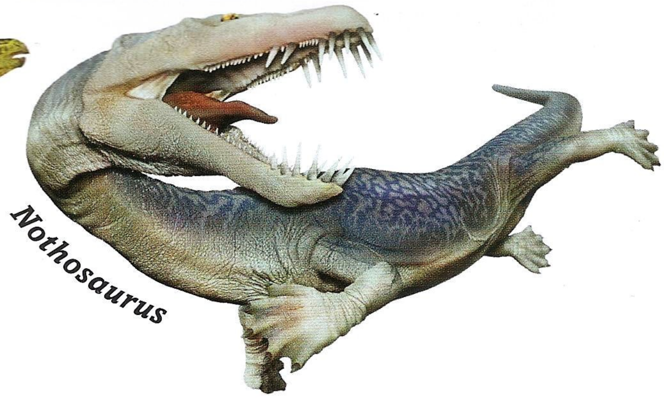


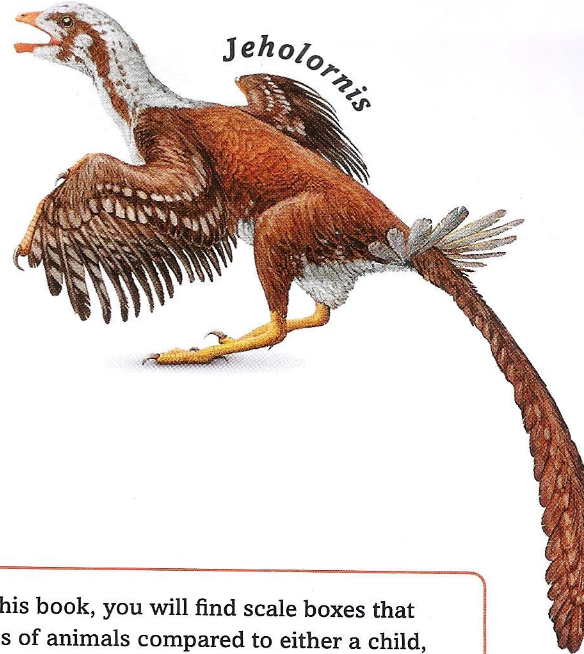
Foreword

The amazing variety of life that exists on our planet is so rich that new kinds of organisms are still being discovered every day. More than 2 million species (types of organisms) have been named and described by scientists, and there are probably millions more waiting to be discovered. But these are only a tiny fraction of the species that have ever existed on Earth in the past. If you were to go back in time 100 million years, you would find yourself surrounded by just as many different animals and plants as today, but—unless you had read this book first—you wouldn't recognize any of them.

Until a little over two centuries ago, no one realized this. They thought that the animals they saw around them had always existed, and that the world hadn't really changed over time. But in the late 18th century, scientists started examining strange shapes found in rocks and realized that they were fossils—the remains of ancient life that had been turned to stone. Most of these fossils were of seashells and other familiar forms, but some were dramatically different—huge bones, skulls, and teeth of gigantic animals that lived millions of years before the dawn of human history.

Using fossils that date right back to the beginning of life on Earth, about 3.8 billion years ago, scientists have been able to piece together most of the history of life. One of the most exciting parts of that story started about 230 million years ago with the earliest dinosaurs. Over the following 164 million years, these animals were to evolve into the most spectacular land animals that have



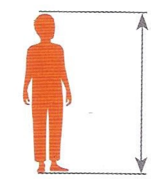


ever walked the Earth. They included gigantic beasts that weighed as much as 12 elephants; terrifying hunters that could bite their way through solid bone; and strange creatures with horns, frills, and even feathers.

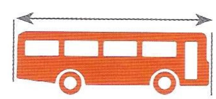
The giant dinosaurs were wiped out in a global catastrophe 66 million years ago. But their fossils survive, along with other fossils that show, beyond doubt, that many of their smaller, feathery relatives were able to fly. Some of these feathered dinosaurs survived the disaster to flourish in the new era as birds. So not only do fossils tell us about life in the distant past, they can also reveal astonishing facts about animals that we see all around us every day.

John Woodward

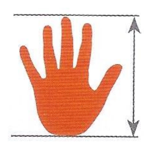
Throughout this book, you will find scale boxes that show the sizes of animals compared to either a child, a school bus, or a human hand.



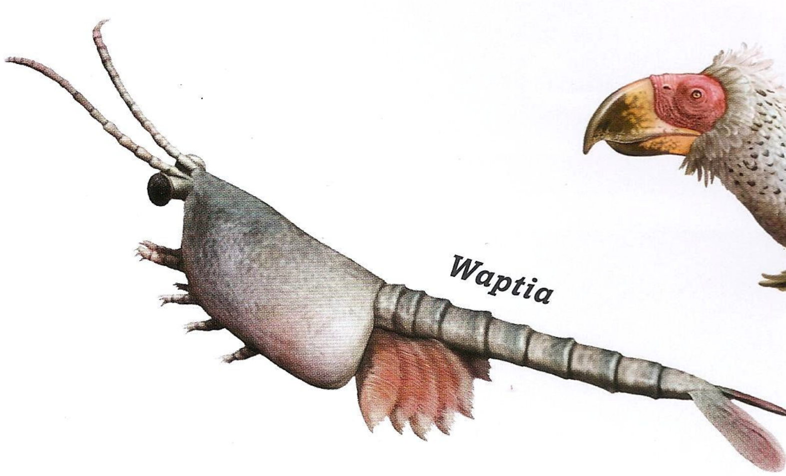
Child = 4 ft 9 in
(1.45 m) tall

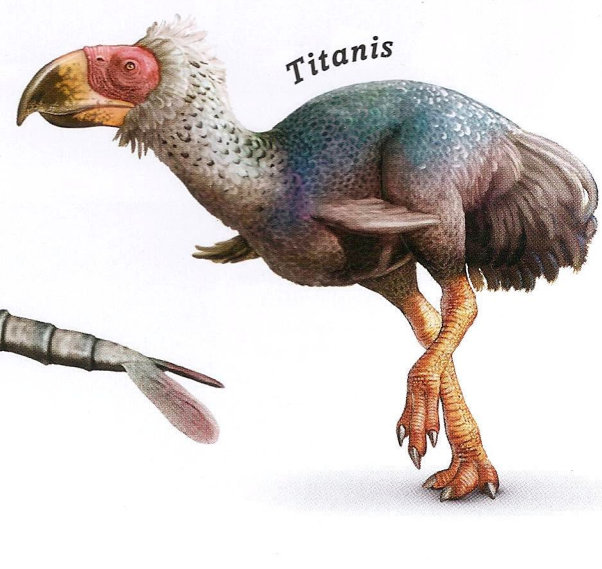


School bus = 36 ft
(11 m) wide



Hand = 6 in
(16 cm) long





Timeline of life

The story of life on Earth is written in the rocks. Over millions of years, sediments like sand and clay settle on the floors of lakes and oceans and harden to form layer after layer of sedimentary rock. Trapped in these ancient deposits are the fossilized remains of prehistoric organisms, with each layer capturing a snapshot of life from a different period in history.

KEY

Early Earth

Paleozoic Era

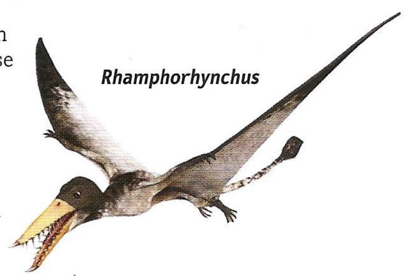
Mesozoic Era

Cenozoic Era

Million years ago **MYA**

251–200 MYA

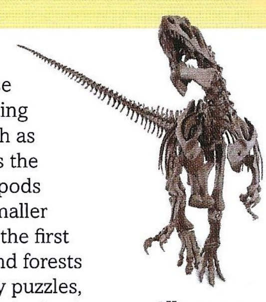
Triassic
Reptiles ruled the world in the Triassic. They gave rise to the first dinosaurs, the first flying reptiles, and the first true mammals, which were little bigger than shrews. Crocodiles and turtles appeared, and the giant aquatic reptiles cruised the ocean.



Rhamphorhynchus

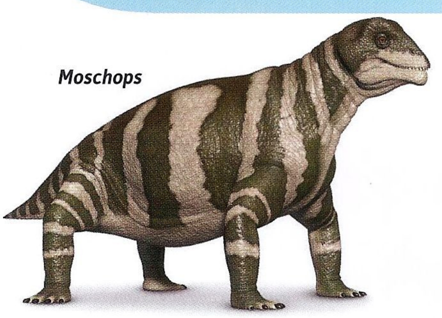
200–145 MYA

Jurassic
The Jurassic saw the rise of the colossal plant-eating sauropod dinosaurs such as *Brachiosaurus*, as well as the giant meat-eating theropods that preyed on them. Smaller theropods evolved into the first birds. Deserts shrank and forests of conifer trees, monkey puzzles, and ferns spread across the land.

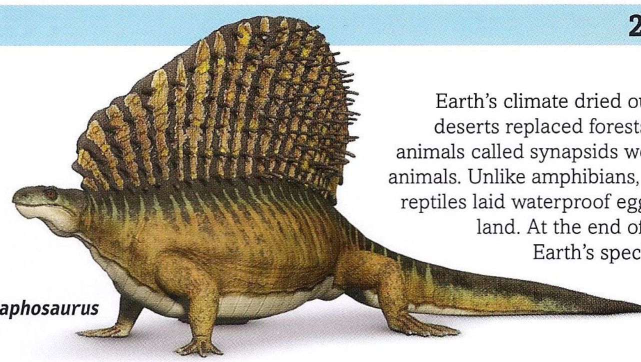


Allosaurus

299–251 MYA



Moschops



Edaphosaurus

Permian
Earth's climate dried out in the Permian, and deserts replaced forests. Reptiles and related animals called synapsids were the dominant land animals. Unlike amphibians, which breed in water, reptiles laid waterproof eggs and could breed on land. At the end of the Permian, most of Earth's species were wiped out by a catastrophe of unknown cause.

4.6–0.5 billion years ago

Precambrian
The Precambrian is a supereon that makes up nearly nine-tenths of Earth's history. For most of it, the only life forms were single-celled organisms in the ocean, such as cyanobacteria. Fossilized imprints of much larger, leaf-shaped organisms that might have been animals appeared about 600 million years ago. Known as the Ediacaran organisms, these life forms vanished at the end of the Precambrian.

Cyanobacteria

542–488 MYA

Cambrian
A wide range of new animal fossils appear in rocks from the Cambrian Period. A sudden burst of evolution—the Cambrian explosion—seems to have produced animals with the first limbs, heads, sense organs, shells, and exoskeletons. All the major categories of invertebrate alive today originated in the Cambrian, from mollusks and arthropods to echinoderms such as *Helicoplacus* (a relative of starfish).

Helicoplacus

Geological periods

Earth's history stretches back 4.6 billion years. This vast span of time is divided into long sections called eras, which are divided in turn into shorter sections called periods. The Jurassic Period, for instance, is when many of the dinosaurs lived. The periods are named after different bands of sedimentary rock, each of which has a distinctive collection of fossils.

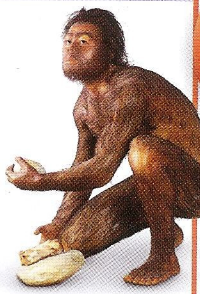
▸23–2 MYA

Neogene
Mammals and birds evolved into recognizably modern forms in the Neogene. Our ape ancestors left the trees and adapted to life in grasslands by walking on two legs.

Dryopithecus

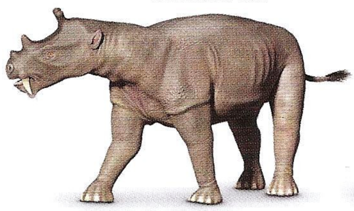
▸2 MYA to present

Quaternary
Our ancestors evolved larger brains in this period and invented ever more ingenious tools to hunt, make fire, build homes, sew clothes, and farm the land.

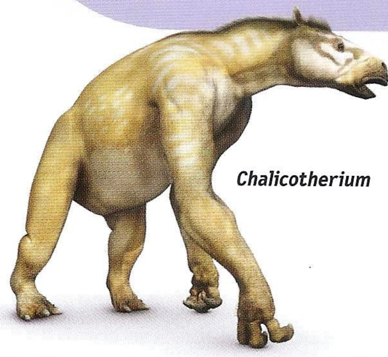


Homo habilis

66–23 MYA◂



Uintatherium

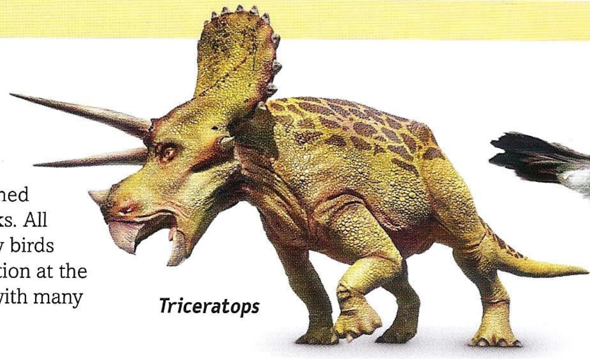


Chalicotherium

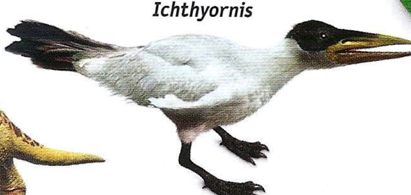
Paleogene
The death of the giant dinosaurs allowed mammals to take their place. They evolved from small nocturnal creatures into a great diversity of land and sea animals, including giant herbivores such as *Chalicotherium*, which used its long arms to reach the highest branches of trees.

▸145–66 MYA

Cretaceous
Dinosaurs of the Cretaceous included *Tyrannosaurus* and the plant-eating ceratopsians, which had distinctive horned faces, neck frills, and beaks. All dinosaurs except for a few birds perished in a mass extinction at the end of the period, along with many other prehistoric animals.



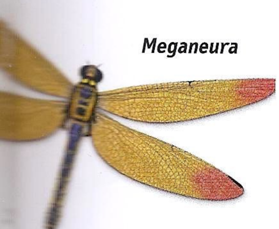
Triceratops



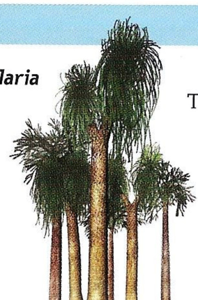
Ichthyornis

Magnolia

358–299 MYA◂



Meganeura

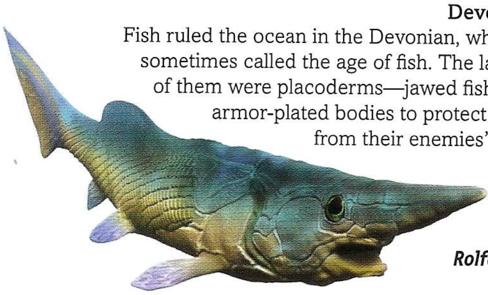


Sigillaria

Carboniferous
This period gets its name from the carbon deposits found in its rock as coal. Coal is the fossilized remains of lush rainforests that covered the land. These were home to giant millipedes, giant dragonflylike insects, and early amphibians, which had evolved from Devonian fish.

416–358 MYA◂

Devonian
Fish ruled the ocean in the Devonian, which is sometimes called the age of fish. The largest of them were placoderms—jawed fish with armor-plated bodies to protect them from their enemies' jaws.



Rolfosteus

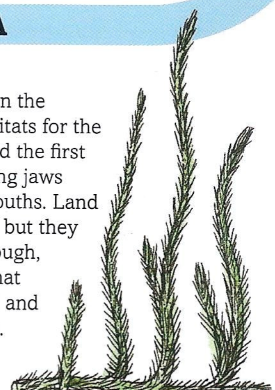
▸488–444 MYA

Ordovician
Warm waters covered much of Earth in the Ordovician, submerging the continent that would later form North America. The oceans teemed with trilobites—large, pillbug-shaped creatures that scuttled across the seabed or swam shrimplike through the water. The first fish and starfish appeared, and simple plants probably began to colonize the land.

Trilobite fossils

▸444–416 MYA

Silurian
Coral reefs flourished in the Silurian, providing habitats for the first fish with bones and the first fish with powerful, biting jaws rather than sucking mouths. Land plants remained small, but they began to acquire the tough, water-carrying veins that would later form wood and trigger the rise of trees.



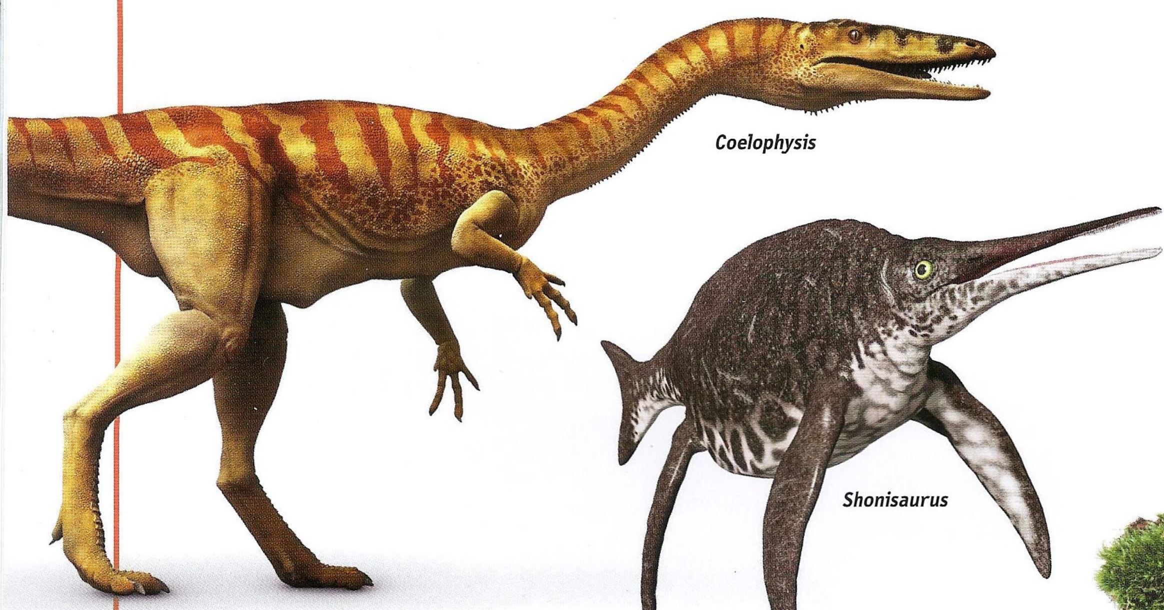
Baragwanathia

Changing planet

251–200 million years ago

If you were to travel back in time to the Mesozoic Era—the age of dinosaurs—Earth would seem like an alien world. The continents had different shapes, the climate was hotter, and strange prehistoric plants covered much of the land. Dinosaurs and their prehistoric relatives ruled this world for nearly 200 million years. The vast span of time is divided into three different periods, each with its own distinct animal and plant life: the Triassic, the Jurassic, and the Cretaceous.

Horsetail



Coelophysis

Shonisaurus

Ginkgo

Moss

Placerias

Triassic world

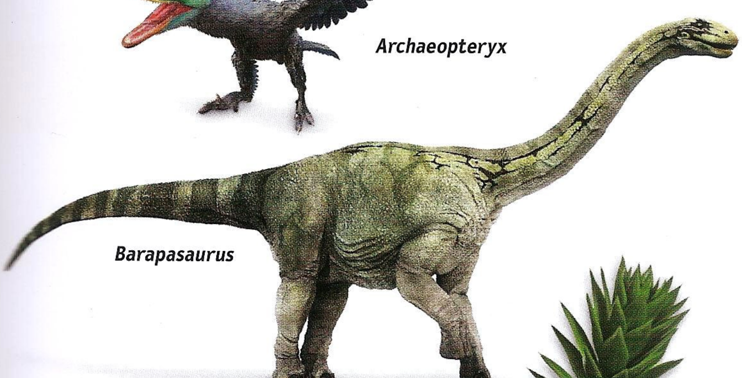
At the start of the Triassic Period, the continents were joined in a single supercontinent called Pangea. Its interior was desert, but the climate was wetter near the coast, allowing forests of ginkgo trees and giant horsetails to grow. The first dinosaurs—small, two-legged meat-eaters—appeared in the Triassic. They coexisted with stocky, tusked, plant-eating animals such as *Placerias*—a relative of early mammals.

200–145 million years ago

Jurassic world

The giant continent of Pangea split during the Jurassic, torn apart by volcanic forces from deep inside Earth, and formed two large new continents. Moist sea air could now carry rain to more of the land, allowing forests to replace desert. Dinosaurs became the dominant land animals, and some evolved into giants, such as *Barapasaurus*, a long-necked plant-eater. The first feathered and flying dinosaurs evolved, including *Archaeopteryx*, a birdlike predator.

Archaeopteryx

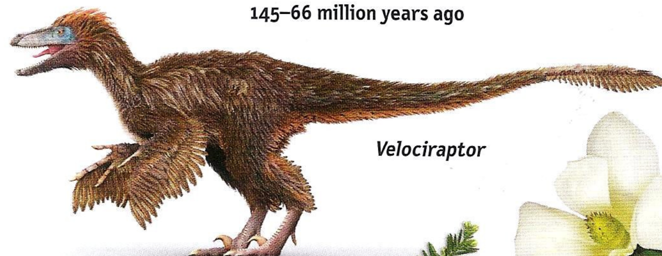


Barapasaurus

Cycad

Fern

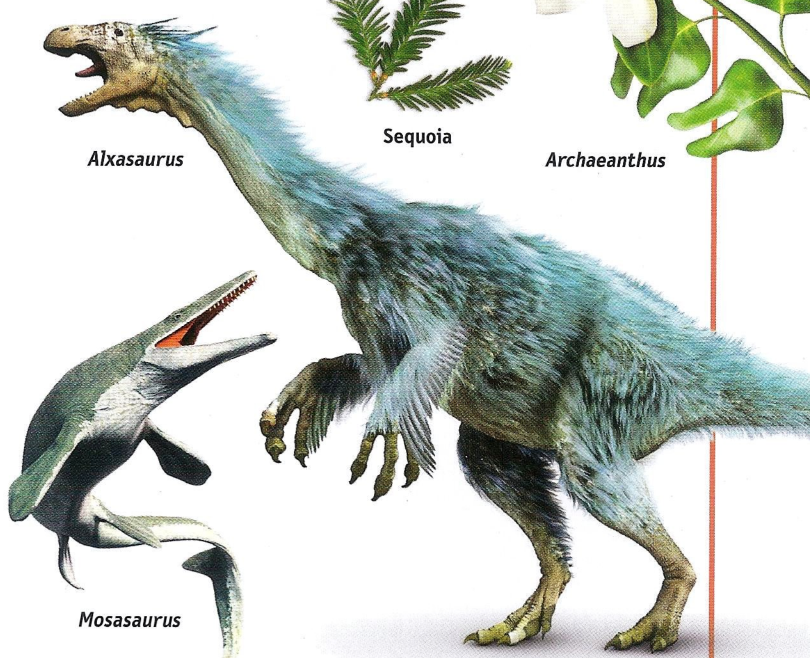
145–66 million years ago



Velociraptor

Sequoia

Archaeanthus



Alxasaurus

Mosasaurus

Cretaceous world

During the Cretaceous, the continents drifted toward their current configuration, moving about as fast as your toenails grow. Flowering plants, which had appeared in the Jurassic, evolved into trees and replaced older vegetation. There were now more kinds of dinosaurs than ever, including *Velociraptor*, a small carnivore with lethal, hooklike claws on its hind feet, and *Alxasaurus*, a feathered herbivore.

Types of fossils

Most of what we know about prehistoric life comes from fossils—the remains of ancient organisms entombed in rock. The study of fossils and the sedimentary rocks containing them has enabled scientists to piece together a record of life on Earth.

Natural cast

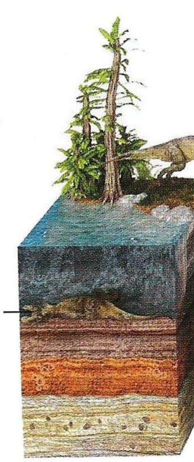
Fossils can form in various ways. Some of the most common fossils are casts—replicas of a whole body or a body part that formed from minerals building up inside a cavity. This ammonite cast formed when minerals built up inside the animal's spiral shell after its soft inner tissues decayed.

Ammonite cast

How fossils form

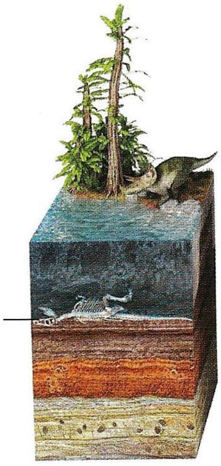
Only a tiny fraction of the animals that lived in the past left fossils behind. Fossils of land animals are especially rare because they form only in unusual circumstances. The animal must die in a place where its body is undisturbed and scavengers can't easily consume it. Mud or sand needs to cover the remains, which must stay buried for millions of years as they slowly turn to rock. Geological forces must then bring the fossil back to the surface, where it can be found.

The body of a drowned Tyrannosaurus sinks to the muddy floor of a delta, where a river meets the sea.



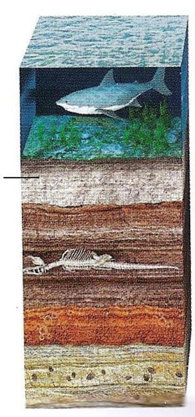
Dinosaur drowns

The flesh slowly rots away, leaving behind hard body parts such as bones and teeth.



Flesh decays

Thousands of years later, layers of mud and sand have buried the skeleton.

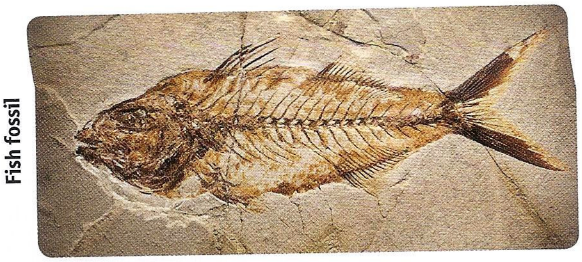


Sediment builds up

Archosaur footprint

Trace fossil

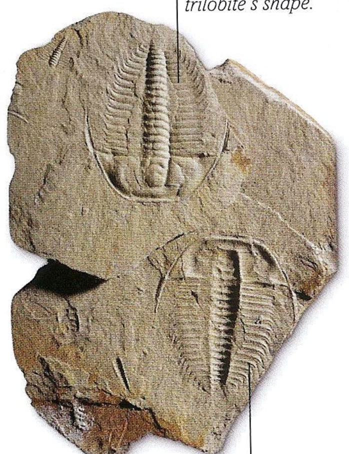
Fossils that record an organism's activity—such as footprints, burrows, nests, or droppings—are known as trace fossils. Fossil footprints help us understand how animals moved.



Fish fossil

Mineralization

Most fossils involve a process called mineralization. Water seeping through the sediment dissolves remains such as bone and deposits crystallized rock minerals in their place, slowly turning the bones to rock.



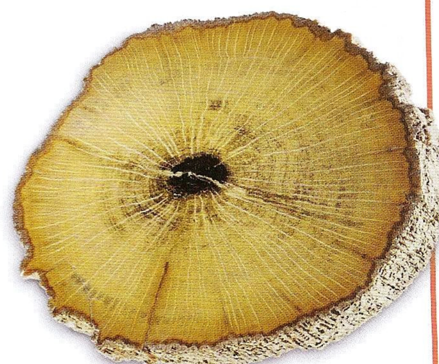
This cast fossil replicates a trilobite's shape.

This mold fossil preserves an impression of a trilobite's body.

Trilobite mold

Mold

Mold fossils form in the same way as casts, but they preserve an imprint of the body rather than a replica of its shape. Trilobites were common sea creatures that grew by shedding their outer skeletons, leaving millions of fossils behind.



Petrified tree

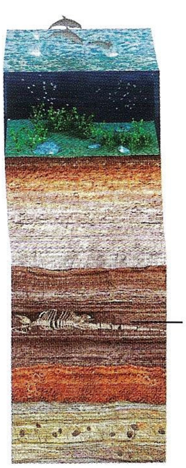
Prehistoric fly in amber

Amber

A few fossils preserve the whole body of a prehistoric animal. Amber is a transparent yellow material formed from fossilized tree resin. It sometimes contains tiny animals that became trapped in the sticky resin as it oozed from a tree.

Petrification

Whole tree trunks can be fossilized by a process called petrification, which preserves minute details. First, groundwater seeping through buried wood deposits crystals of silica inside tiny spaces. Then, more slowly, minerals gradually replace the wood fibers, turning the trunk to stone.

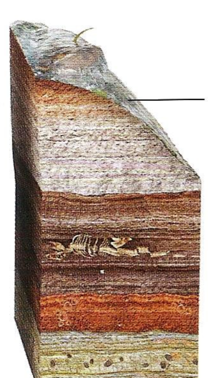


Water seeping through the layers replaces the bones with rock minerals, turning the fossil to rock.

Bones turn to rock

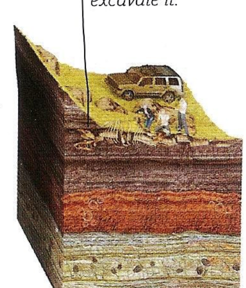
Millions of years later, the continents have moved and the dinosaur fossil is no longer under the sea.

Continents move



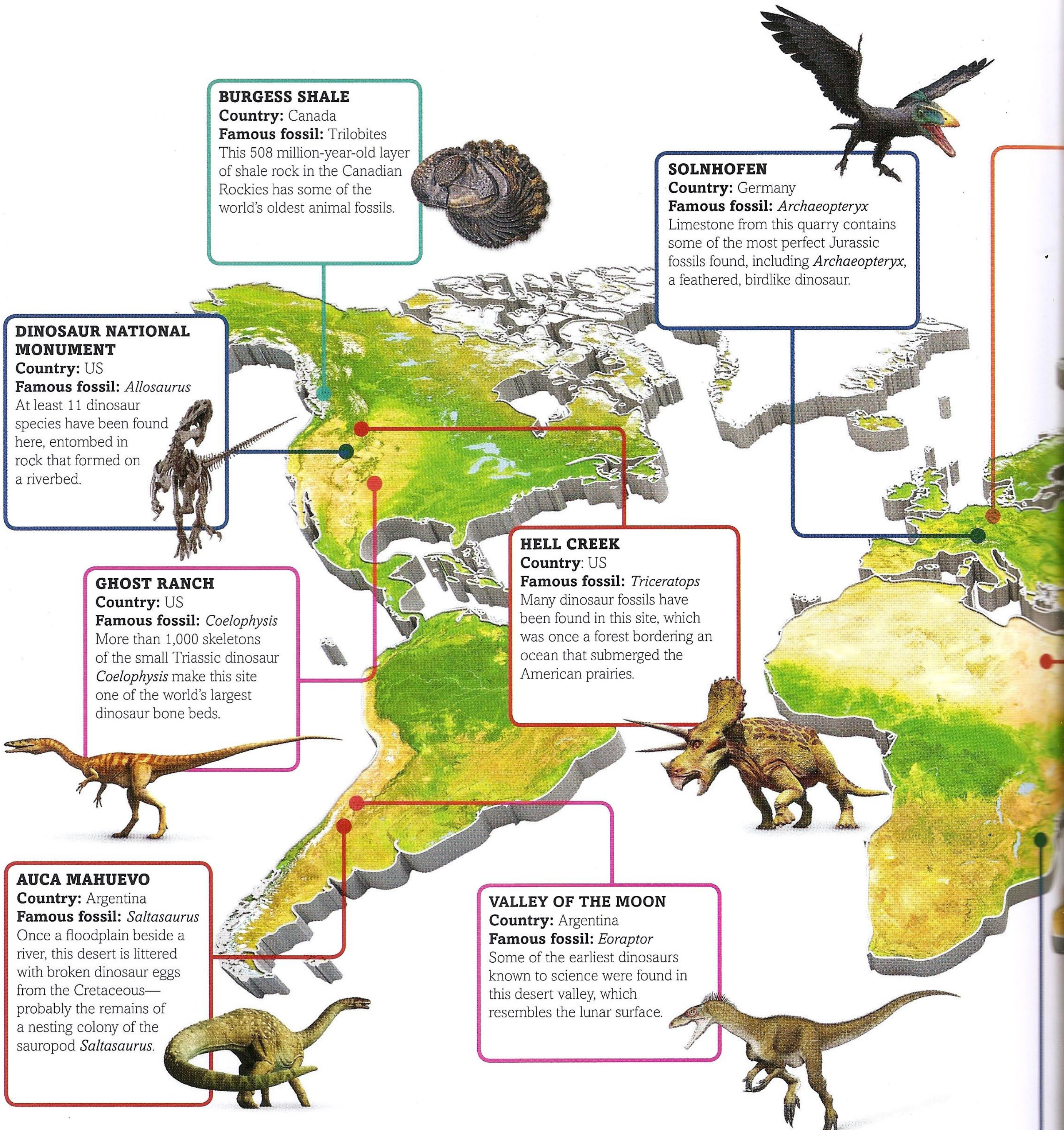
Glaciers or other processes erode the ground, wearing away the sedimentary rock.

Erosion of surface



Erosion finally reveals the fossil, allowing paleontologists to excavate it.

Discovery



BURGESS SHALE
Country: Canada
Famous fossil: Trilobites
This 508 million-year-old layer of shale rock in the Canadian Rockies has some of the world's oldest animal fossils.

SOLNHOFEN
Country: Germany
Famous fossil: *Archaeopteryx*
Limestone from this quarry contains some of the most perfect Jurassic fossils found, including *Archaeopteryx*, a feathered, birdlike dinosaur.

DINOSAUR NATIONAL MONUMENT
Country: US
Famous fossil: *Allosaurus*
At least 11 dinosaur species have been found here, entombed in rock that formed on a riverbed.

HELL CREEK
Country: US
Famous fossil: *Triceratops*
Many dinosaur fossils have been found in this site, which was once a forest bordering an ocean that submerged the American prairies.

GHOST RANCH
Country: US
Famous fossil: *Coelophysis*
More than 1,000 skeletons of the small Triassic dinosaur *Coelophysis* make this site one of the world's largest dinosaur bone beds.

AUCA MAHUEVO
Country: Argentina
Famous fossil: *Saltasaurus*
Once a floodplain beside a river, this desert is littered with broken dinosaur eggs from the Cretaceous—probably the remains of a nesting colony of the sauropod *Saltasaurus*.

VALLEY OF THE MOON
Country: Argentina
Famous fossil: *Eoraptor*
Some of the earliest dinosaurs known to science were found in this desert valley, which resembles the lunar surface.

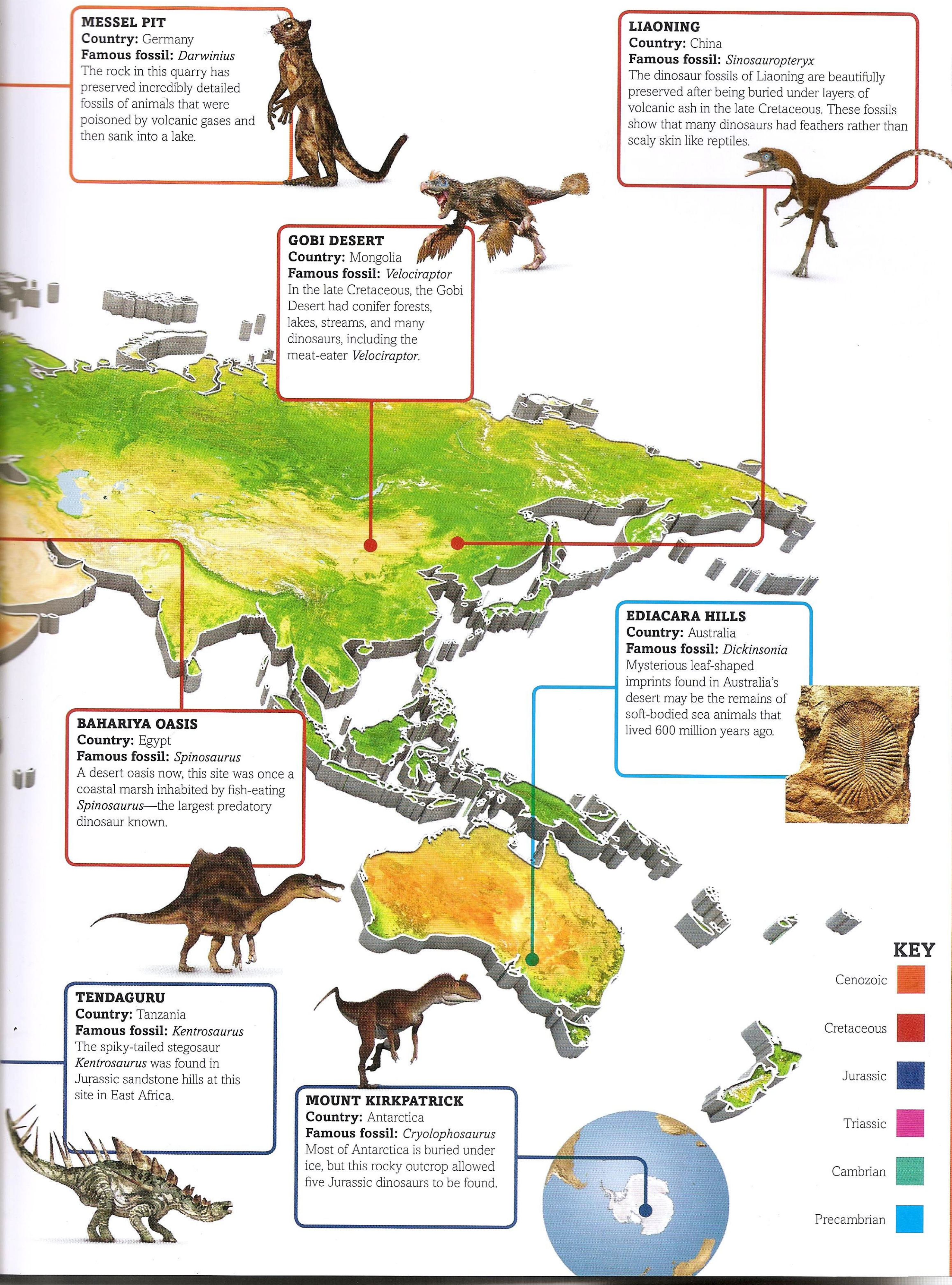
Fossil finds

Most fossils are found in sedimentary rock that formed from ancient layers of mud and sand. Sedimentary rock is found worldwide, but a few key sites have especially clear fossils of animals that didn't fully decay, preserving fine details like feathers or skin. Many fossils are found in deserts, not because animals fossilize well in deserts, but because the large expanses of exposed rock make fossils easier to spot.

MESSEL PIT
Country: Germany
Famous fossil: *Darwinius*
The rock in this quarry has preserved incredibly detailed fossils of animals that were poisoned by volcanic gases and then sank into a lake.

LIAONING
Country: China
Famous fossil: *Sinosauropteryx*
The dinosaur fossils of Liaoning are beautifully preserved after being buried under layers of volcanic ash in the late Cretaceous. These fossils show that many dinosaurs had feathers rather than scaly skin like reptiles.

GOBI DESERT
Country: Mongolia
Famous fossil: *Velociraptor*
In the late Cretaceous, the Gobi Desert had conifer forests, lakes, streams, and many dinosaurs, including the meat-eater *Velociraptor*.



EDIACARA HILLS
Country: Australia
Famous fossil: *Dickinsonia*
Mysterious leaf-shaped imprints found in Australia's desert may be the remains of soft-bodied sea animals that lived 600 million years ago.

BAHARIYA OASIS
Country: Egypt
Famous fossil: *Spinosaurus*
A desert oasis now, this site was once a coastal marsh inhabited by fish-eating *Spinosaurus*—the largest predatory dinosaur known.

TENDAGURU
Country: Tanzania
Famous fossil: *Kentrosaurus*
The spiky-tailed stegosaur *Kentrosaurus* was found in Jurassic sandstone hills at this site in East Africa.

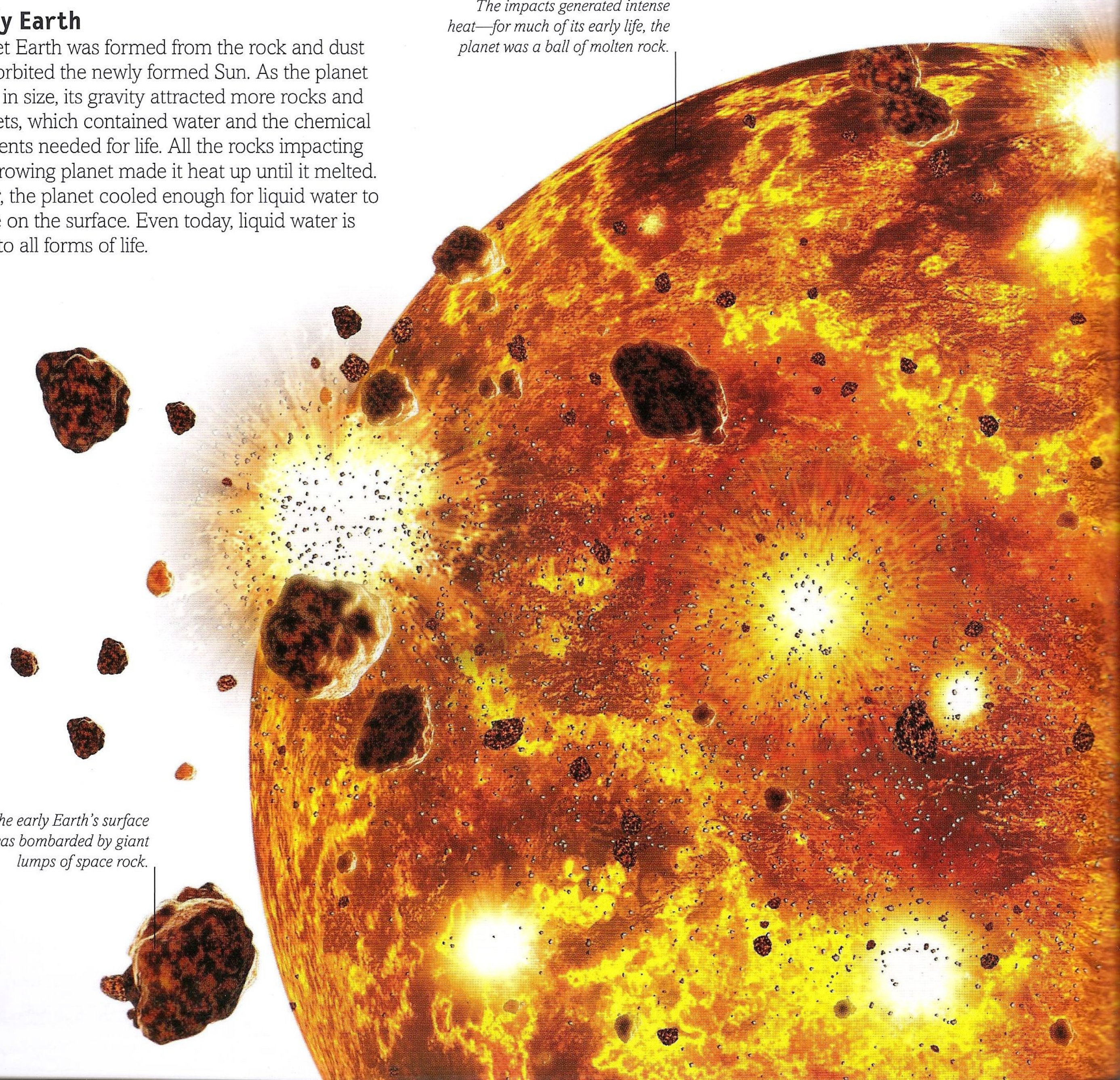
MOUNT KIRKPATRICK
Country: Antarctica
Famous fossil: *Cryolophosaurus*
Most of Antarctica is buried under ice, but this rocky outcrop allowed five Jurassic dinosaurs to be found.

Origin of life

Life on Earth began at least 3.5 billion years ago, and possibly more than 4 billion years ago. These oldest-known life forms were microscopic single cells that lived in water—tiny capsules of watery fluid containing the complex chemicals vital to all types of life. How these cells formed is still not known, but the process was probably fueled by the heat and chemical energy of hot springs, either on land or on the deep ocean floor.

Early Earth

Planet Earth was formed from the rock and dust that orbited the newly formed Sun. As the planet grew in size, its gravity attracted more rocks and comets, which contained water and the chemical elements needed for life. All the rocks impacting the growing planet made it heat up until it melted. Later, the planet cooled enough for liquid water to settle on the surface. Even today, liquid water is vital to all forms of life.

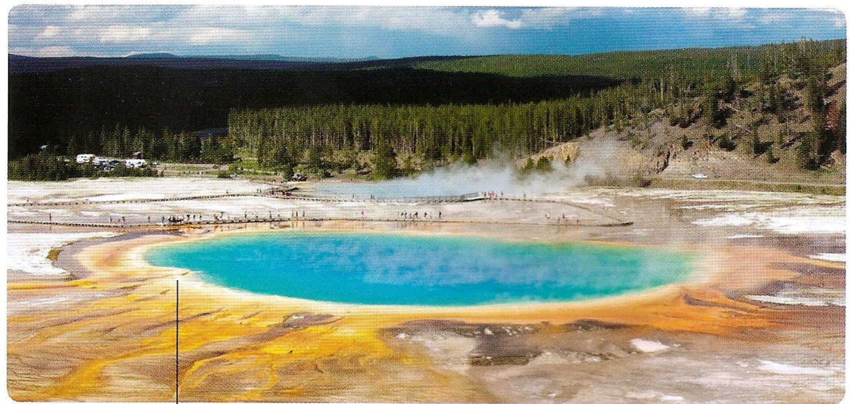


The impacts generated intense heat—for much of its early life, the planet was a ball of molten rock.

The early Earth's surface was bombarded by giant lumps of space rock.

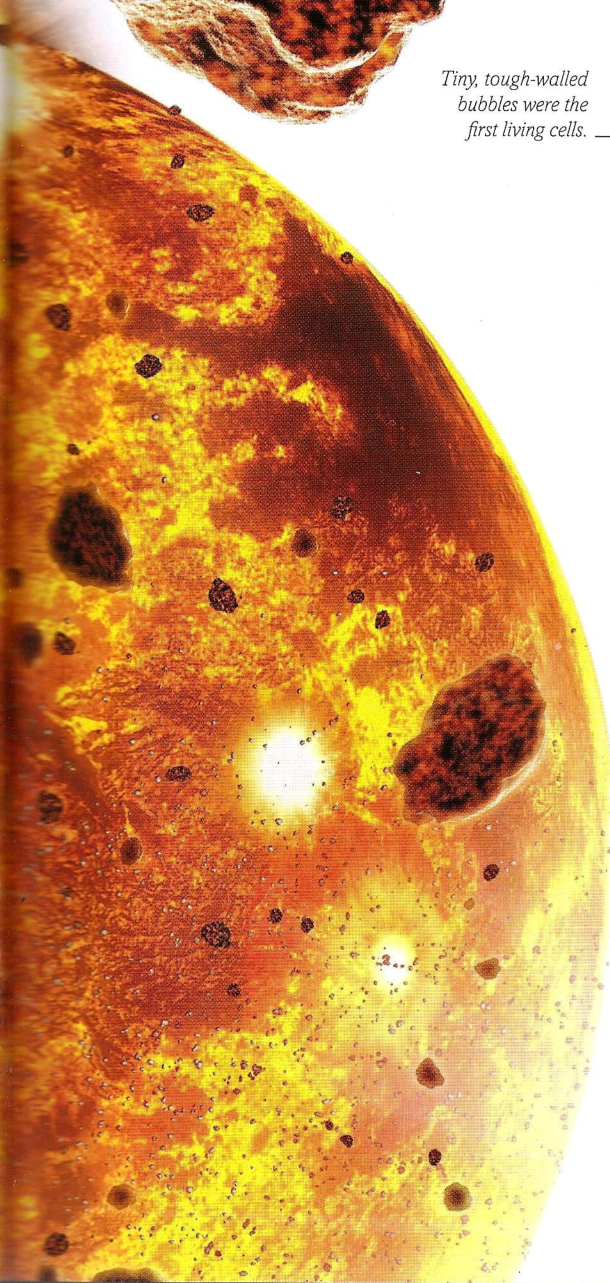
First life

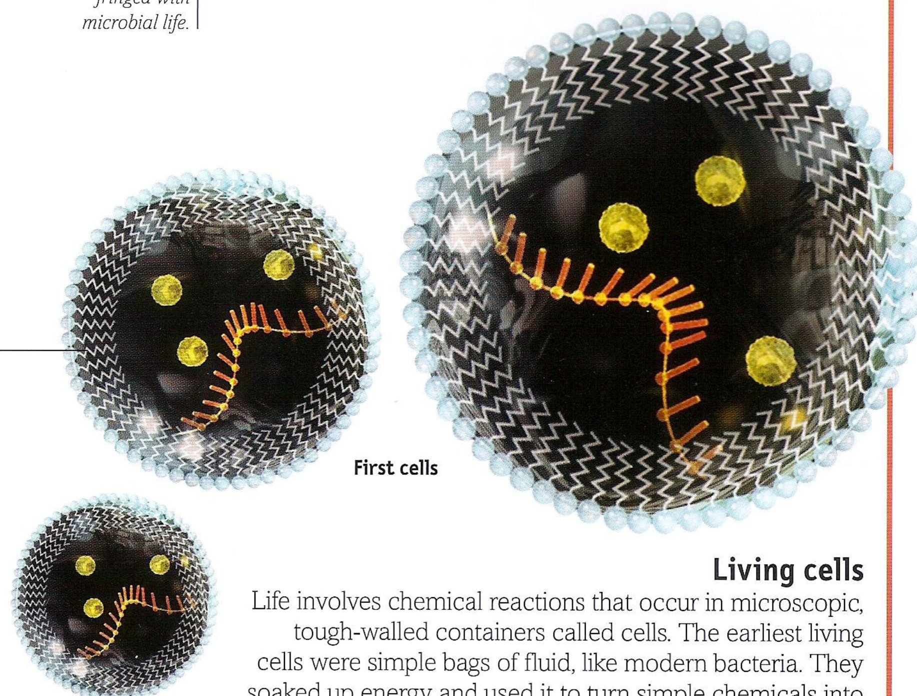
The first living organisms must have formed in water containing simple chemicals dissolved from rocks. Today, this type of chemical-rich water erupts from hot springs on the ocean floor and in places like Yellowstone National Park. The water contains microscopic organisms that resemble some of the earliest living things, so it is likely that life began in such places. It is this microbial life that gives Grand Prismatic Spring its vibrant colors.



Grand Prismatic Spring, Yellowstone National Park

The hot spring is fringed with microbial life.





Tiny, tough-walled bubbles were the first living cells.

First cells

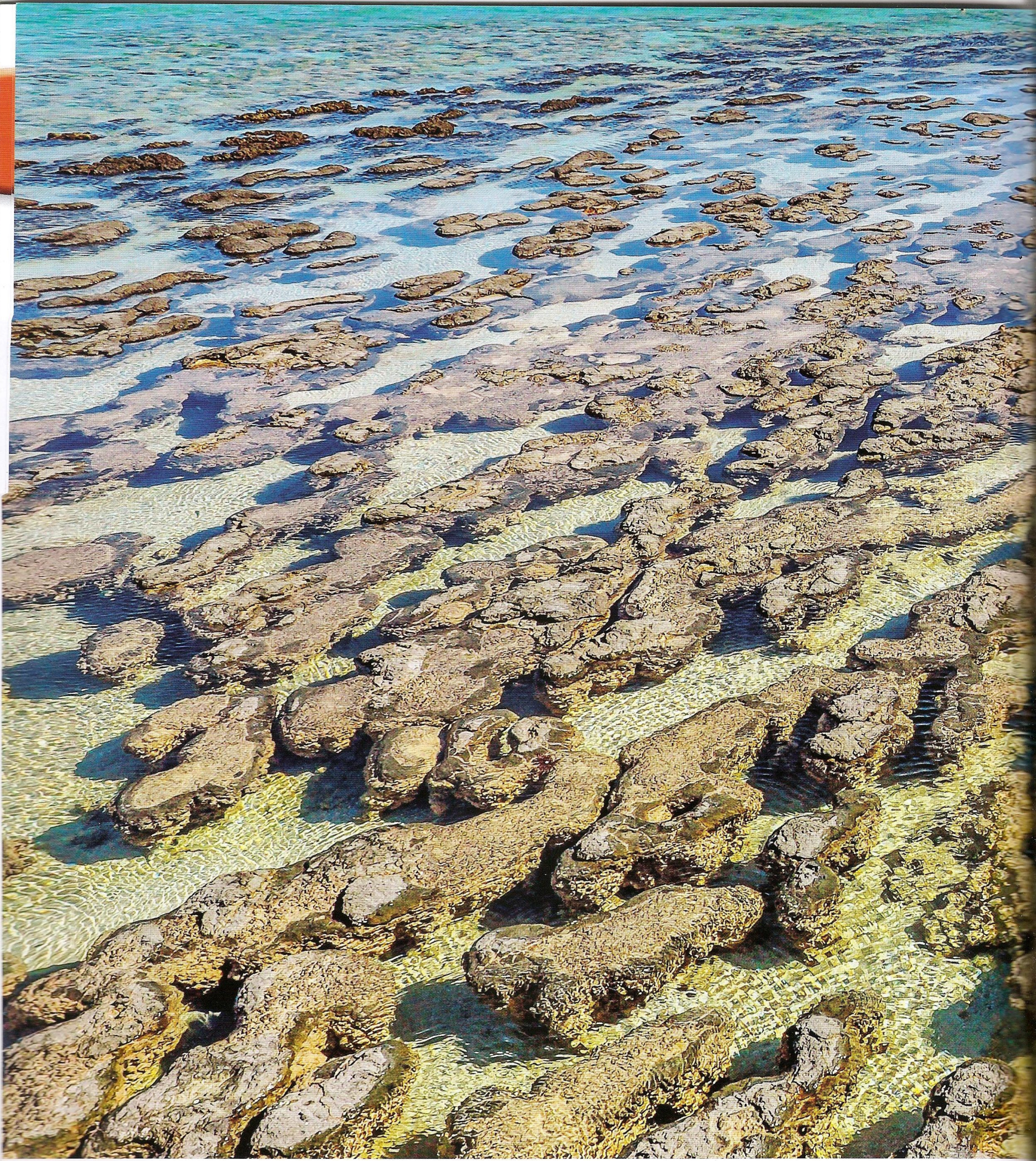
Living cells

Life involves chemical reactions that occur in microscopic, tough-walled containers called cells. The earliest living cells were simple bags of fluid, like modern bacteria. They soaked up energy and used it to turn simple chemicals into complex substances vital to life, such as proteins. This helped them grow, multiply, and form large colonies like the ones that live around hot springs today.

Evidence of early life

The oldest-known rocks on Earth contain microscopic structures that have been identified as fossil Archaea—organisms similar to bacteria. The rocks, which formed on the ocean floor, are at least 3.8 billion years old. But much clearer evidence of early life exists in the form of fossil stromatolites. Dating from about 3.4 billion years ago, these were once colonies of microbes called cyanobacteria that built up in dome-shaped layers. These layers are clearly visible in the fossils.

Stromatolite fossil



GAME-CHANGERS The shallow waters of Shark Bay in Western Australia support a life form that has existed on Earth for billions of years—stromatolites. These muddy-looking lumps have been built up by cyanobacteria—simple microbes that turn air and water into sugar using sunlight. This process of photosynthesis creates most of the food that animals need and releases the oxygen they breathe.

When cyanobacteria evolved in the oceans more than 2.5 billion years ago, there was very little oxygen in the air. Over millions of years, they pumped out so much that it now makes up more than a fifth of the atmosphere. This was vital for the evolution of animals, which need oxygen to turn food into energy. So all the animals that have ever lived owe their existence to these microbes. Free-living cyanobacteria are still widespread in oceans and on land, but thriving stromatolites are rare because they were ideal food for some of the animals that evolved in the world they had created. The ones in Shark Bay survive because few animals can live in the very salty water of its lagoons.

Evolution and extinction

Fossils reveal how life has changed over time. This was not fully understood until the 19th century, when fossils became important evidence supporting the theory of evolution by natural selection. Developed primarily by English scientist Charles Darwin, this theory showed that the individuals in a species vary in their ability to cope with the hardships of life—some survive and breed, while others do not. As a result, species gradually change over time as they adapt to the changing world. New species evolve, and older ones may die out completely, becoming extinct.

Fossil evidence

When the first fossil of *Archaeopteryx* showing wing feathers was discovered in 1861, it was seen as powerful evidence in favor of the theory that living things evolve over time.

Bony tail ❯ At first sight, this 150-million-year-old fossil of an *Archaeopteryx* looks very like a living bird, with broad, feathered wings. But it had a long, bony tail like an extinct dinosaur. This combination of features does not exist in any modern animal.

The jagged edges and pattern of lines add to the leaf insect's superb camouflage.

Leaf insect

Natural selection

Every animal is different from its parents. This natural variation produces individuals with different strengths and weaknesses, so some are more likely to survive. An insect with more effective camouflage than its cousins will be more likely to evade hungry birds, breed, and pass on its advantages to its young, Meanwhile, its less well camouflaged relatives may die out.

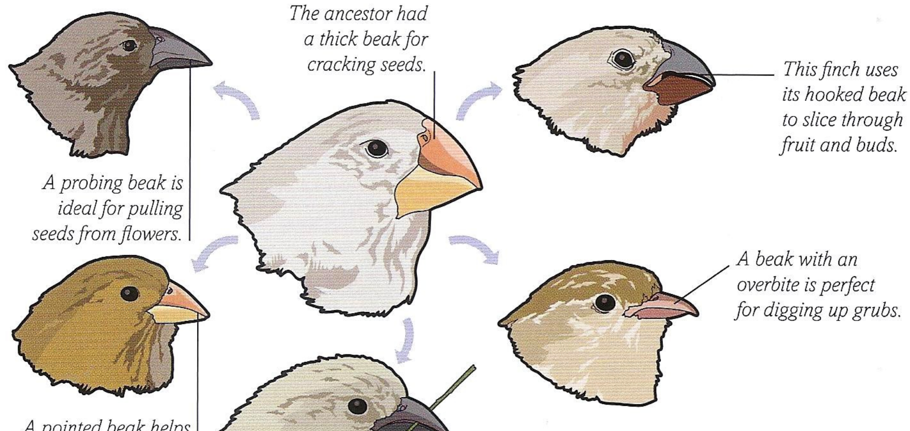
Archaeopteryx

New species

If birds fly to a new habitat, such as an oceanic island, they may face difficulties in finding food. Those that survive will be the ones that, by some stroke of luck, have features that help them cope with the new conditions. If they manage to breed, their young will tend to inherit these features. Over many generations, this may give rise to an island form that is clearly different from its mainland ancestors. This process creates new species.

Wing feathers ❯ The fossils of *Archaeopteryx* preserve traces of feathers that are very similar to those of modern birds. But the fossils also show that it had the teeth and bones of a theropod dinosaur.

Archaeopteryx fossil



Galápagos finches
The Galápagos Islands in the Pacific Ocean are home to several species of finch, each with a beak specialized for a different type of food. It is clear that they all evolved from the same ancestor, which probably arrived from nearby South America.

Lost ancestors

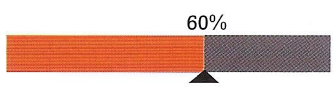
The processes of evolution and extinction cause a relentless turnover of species, with new ones evolving as others die out. This means that, over the past 500 million years, more than 90 percent of all species on Earth have vanished. We only know about these life forms because their remains have survived as fossils.

Trilobite fossil

Mass extinctions

Sometimes a catastrophic event changes the world so radically that very few animals can survive it. This is called a mass extinction. Since life began, there have been five major mass extinctions. Each one wiped out much of the life on Earth at the time, allowing new species to evolve and take over.

ORDOVICIAN (440 MYA)
Up to 60 percent of marine species perished in a mass extinction at the end of the Ordovician Period.

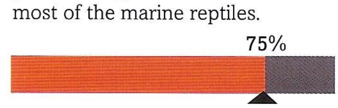


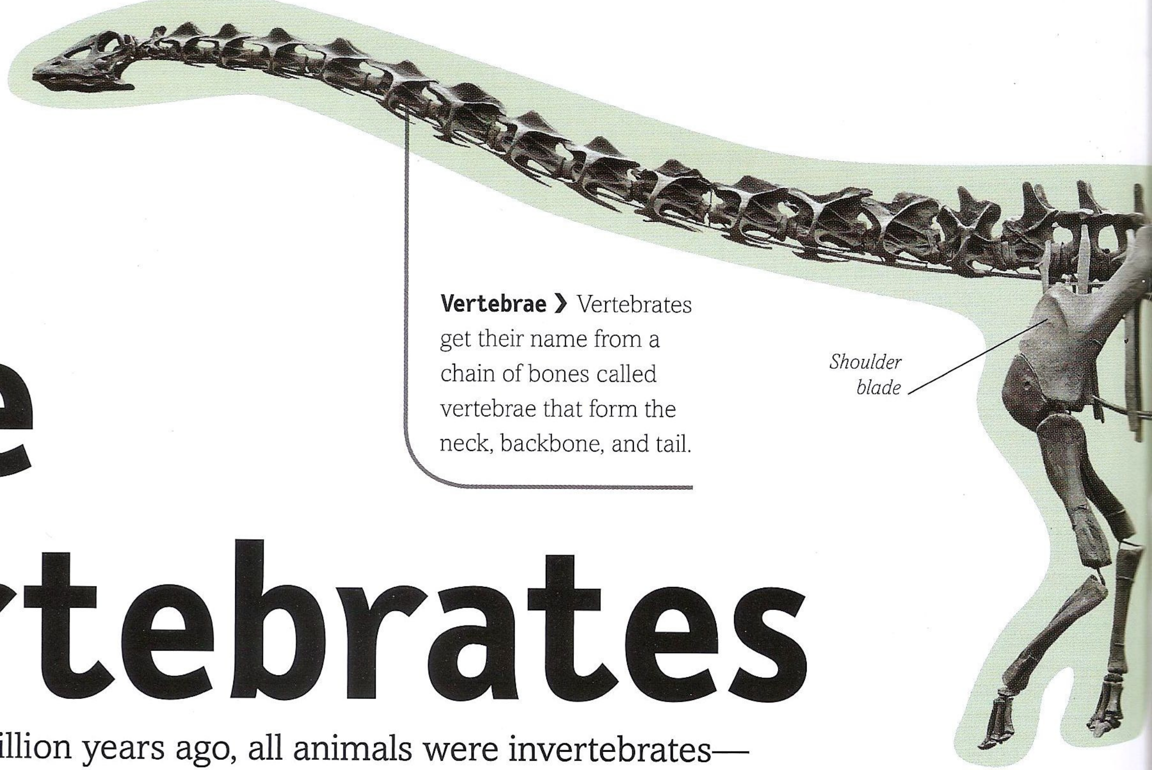
DEVONIAN (358 MYA)
The Late Devonian extinction mainly affected oceanic life, especially in shallow coastal seas.

PERMIAN (250 MYA)
The Permian Period ended with a global catastrophe that almost wiped out all life on Earth.

TRIASSIC (200 MYA)
Many of the animals that coexisted with early dinosaurs died out at the end of the Triassic Period.

CRETACEOUS (66 MYA)
This mass extinction destroyed the pterosaurs, giant dinosaurs, and most of the marine reptiles.

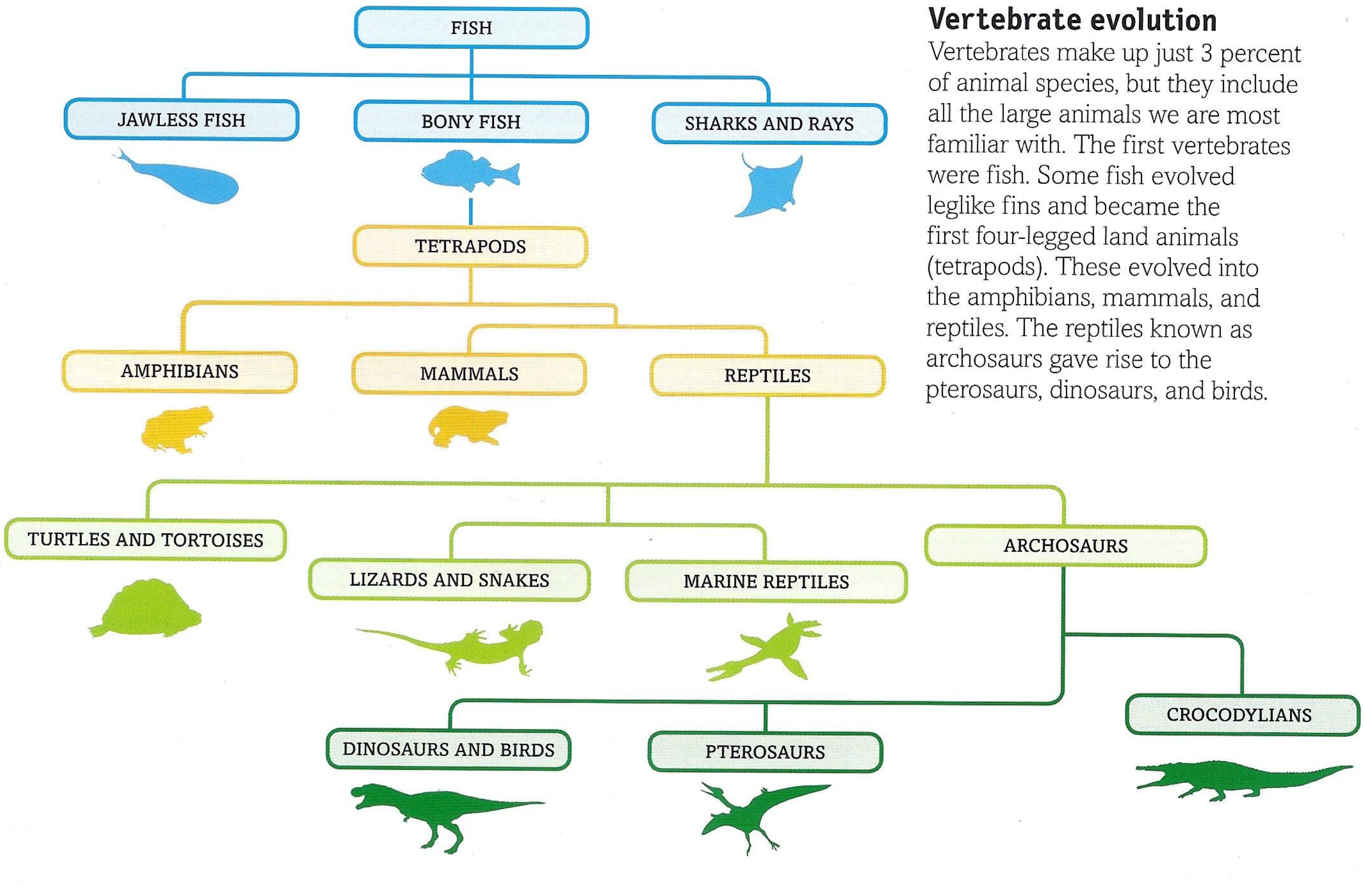




Vertebrae ❯ Vertebrates get their name from a chain of bones called vertebrae that form the neck, backbone, and tail.

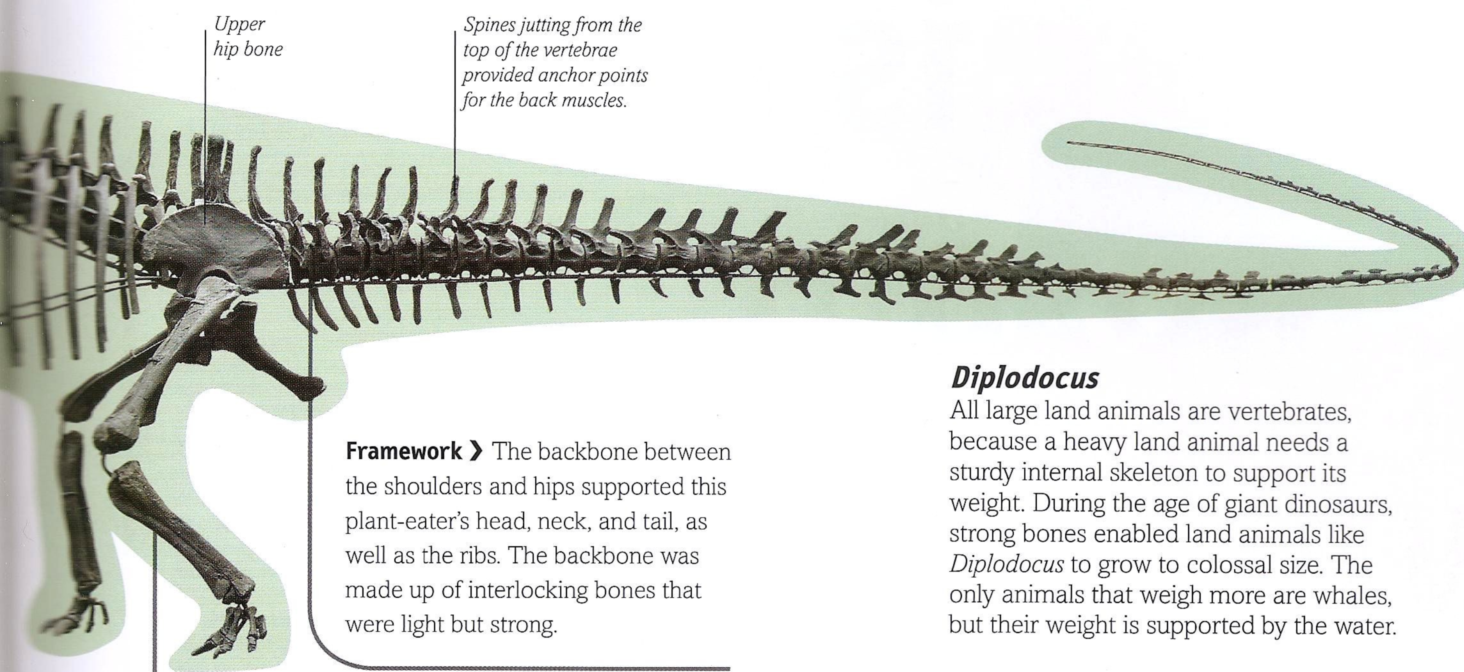
The vertebrates

Until about 530 million years ago, all animals were invertebrates—creatures with no internal jointed skeletons. But then new types of animals appeared in the oceans, with bodies strengthened by a springy rod—the beginnings of a backbone. These evolved into fish—the first true vertebrates and the ancestors of amphibians, mammals, reptiles, and birds.



Vertebrate evolution

Vertebrates make up just 3 percent of animal species, but they include all the large animals we are most familiar with. The first vertebrates were fish. Some fish evolved leglike fins and became the first four-legged land animals (tetrapods). These evolved into the amphibians, mammals, and reptiles. The reptiles known as archosaurs gave rise to the pterosaurs, dinosaurs, and birds.

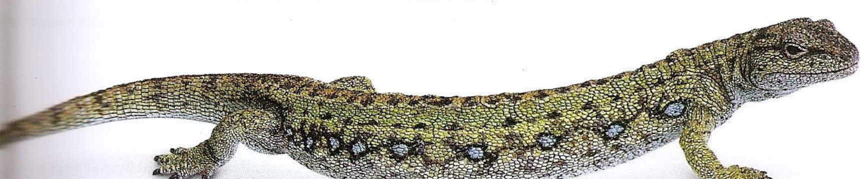


Framework ❯ The backbone between the shoulders and hips supported this plant-eater's head, neck, and tail, as well as the ribs. The backbone was made up of interlocking bones that were light but strong.

Leg bones ❯ The immense weight of this giant dinosaur was supported by massive leg bones, linked to the backbone by strong, mobile joints.

Diplodocus

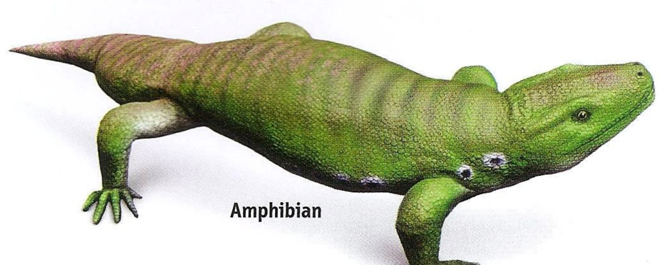
All large land animals are vertebrates, because a heavy land animal needs a sturdy internal skeleton to support its weight. During the age of giant dinosaurs, strong bones enabled land animals like *Diplodocus* to grow to colossal size. The only animals that weigh more are whales, but their weight is supported by the water.


Reptile


Archosaur


Mammal


Fish


Amphibian

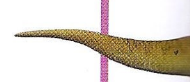
Types of vertebrate

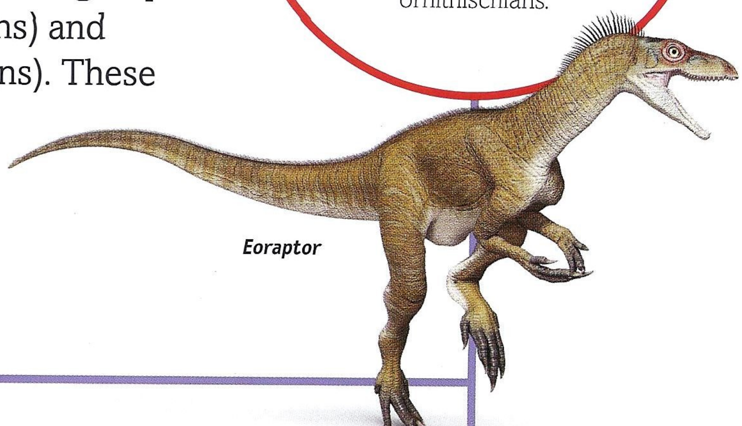
We usually think of the vertebrates as fish, amphibians, reptiles, birds, and mammals. But the birds can also be seen as the most successful and diverse living group of archosaurs, a branch of the reptiles that also included their closest relatives—the extinct dinosaurs.

What is a dinosaur?

Dinosaurs were a diverse and successful group of reptiles that dominated life on land for about 140 million years. Humans, for comparison, have existed for less than 1 million years. Ranging in size from animals no bigger than pigeons to lumbering giants the size of trucks, they were reptiles, but very different from modern reptiles. Dinosaurs can be split into two groups: lizard-hipped dinosaurs (saurischians) and bird-hipped dinosaurs (ornithischians). These can be split further, as shown.

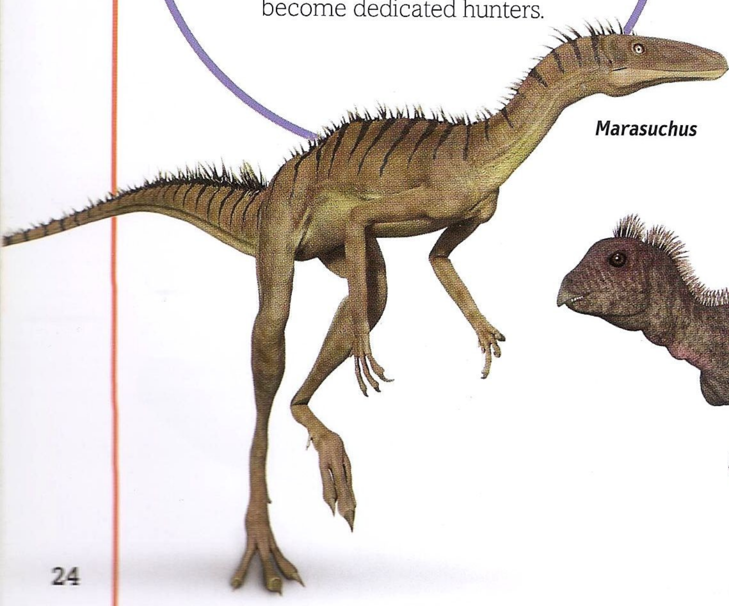
Saurischians
Saurischian ("lizard hipped") refers to the typical saurischians that had hip bones like those of lizards. This group included the sauropodomorph plant-eaters. It may also have included the meat-eating theropods, but some scientists think that theropods are more closely related to ornithischians.





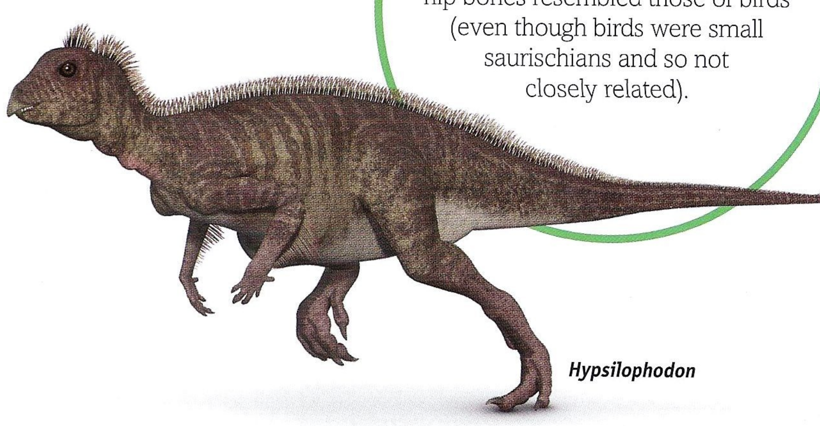
Eoraptor

Ancestral dinosaurs
The first dinosaurs were small, agile animals that ran on two legs—they would have looked like this *Marasuchus*, an early, dinosaurlike archosaur. During the late Triassic Period, early dinosaurs evolved in different ways. Most became specialized for eating plants, but some were to become dedicated hunters.



Marasuchus

Ornithischians
This group is made up of beaked plant-eaters with relatively short necks. The name means "bird hipped," because their hip bones resembled those of birds (even though birds were small saurischians and so not closely related).

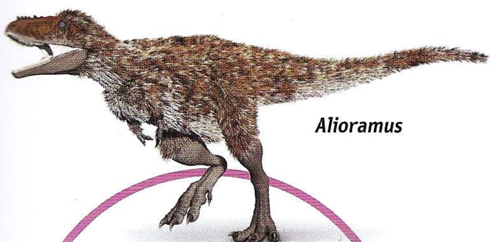


Hypsilophodon

Giraffatitan

Sauropodomorphs

The sauropodomorphs are named after the sauropods—giant, long-necked plant-eaters that did not have beaks and walked on four legs.



Alioramus

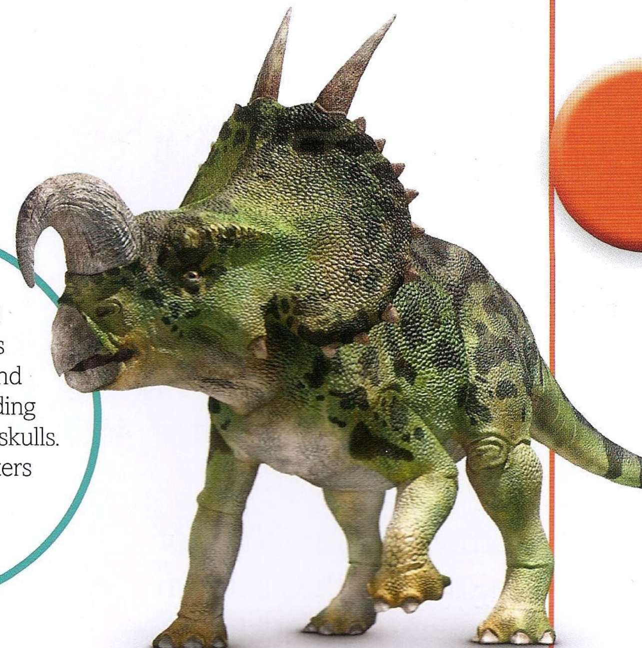
Theropods

Theropods were nearly all meat-eaters that walked on two legs. Some were huge, powerful hunters, but the theropods also include birds.

Marginocephalians

Ceratopsians

Most ceratopsians had horned heads and big, bony frills extending from the back of their skulls. They were plant-eaters with hooked, parrotlike beaks.



Einiosaurus

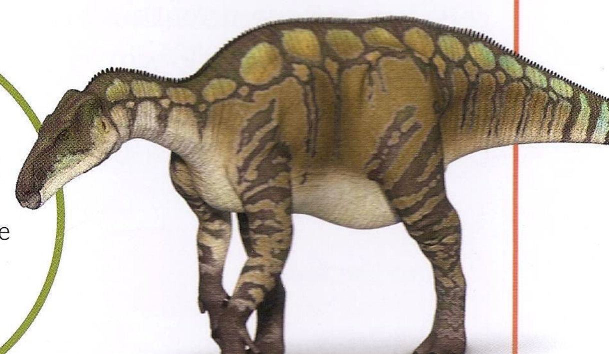
Pachycephalosaurs

These dinosaurs had very thick skulls. They walked on two legs and probably ate a variety of plant and animal food.

Pachycephalosaurus

Ornithopods

The ornithopods were a group of beaked plant-eaters that mostly walked on two feet, but the biggest ones supported some of their weight on their hands.



Iguanodon

Thyreophorans

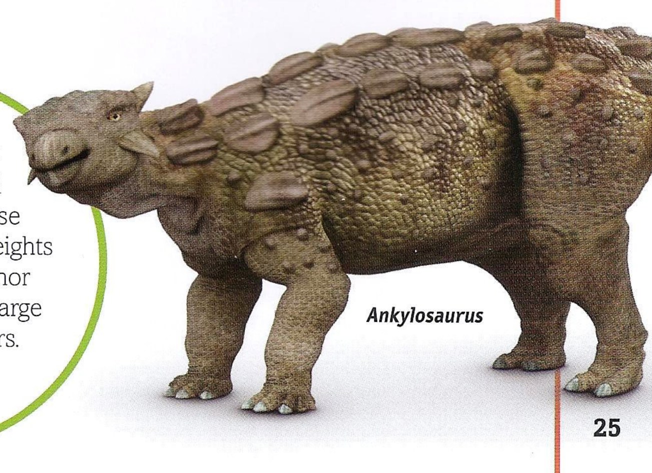
Stegosaurus

Stegosaurs

These beaked, plant-eating dinosaurs had rows of tall plates and spikes extending down their backs and tails. They all walked on four legs.

Ankylosaurs

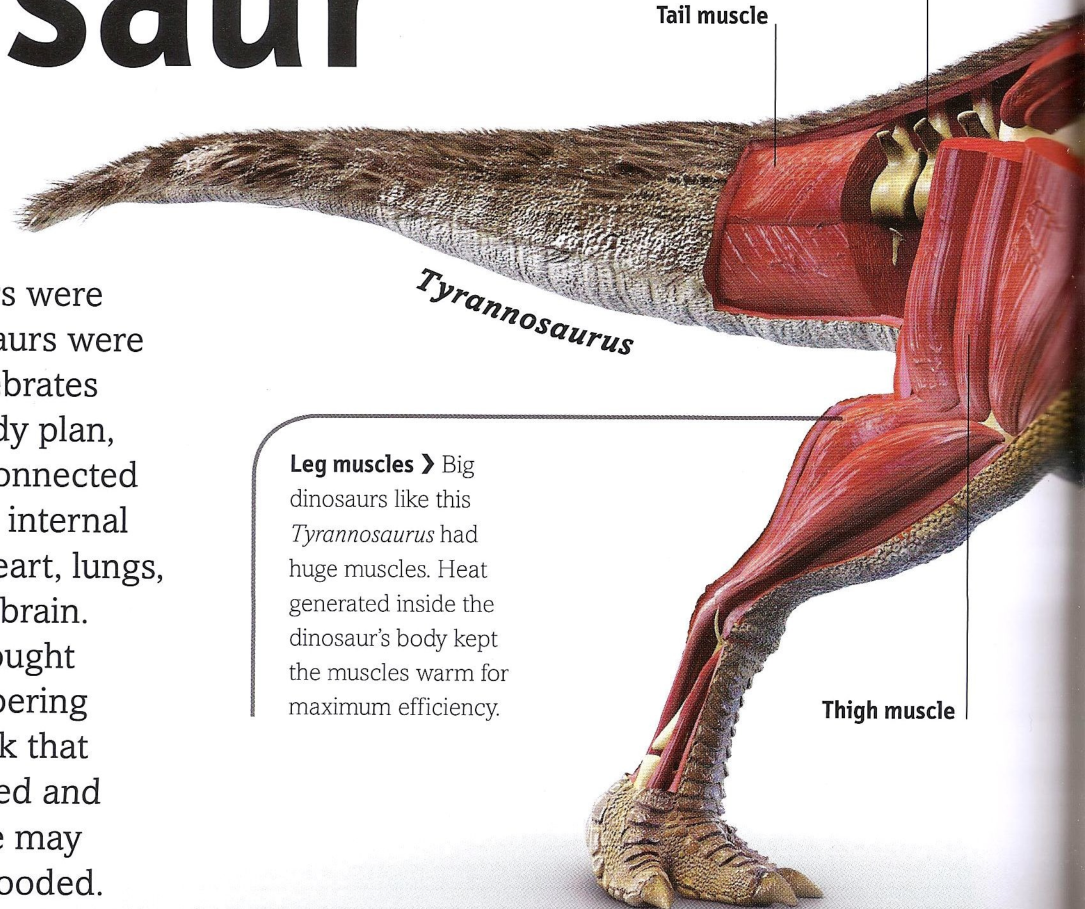
Sometimes called tank dinosaurs, these plant-eating heavyweights had thick body armor for defense against large theropod predators.



Ankylosaurus

Inside a dinosaur

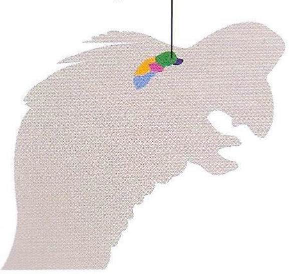
Although soft tissues of animals' bodies seldom fossilize, we can still figure out what dinosaurs were like on the inside. Dinosaurs were vertebrates, and all vertebrates share the same basic body plan, with powerful muscles connected to a jointed skeleton and internal organs that included a heart, lungs, stomach, intestines, and brain. Dinosaurs were once thought to be cold-blooded, lumbering reptiles, but we now think that many were as quick-witted and active as birds, and some may even have been warm-blooded.



Leg muscles ❯ Big dinosaurs like this *Tyrannosaurus* had huge muscles. Heat generated inside the dinosaur's body kept the muscles warm for maximum efficiency.

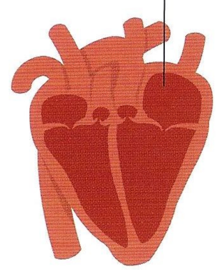
Dinosaur features

The brain of a dinosaur like Citipati *was adapted for sharp senses, not intelligence.*



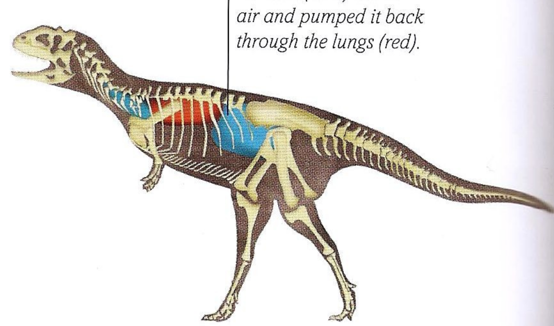
Brain The brains of extinct dinosaurs were relatively small, and some were tiny. Most would not have been as intelligent as modern birds.

The closest living relatives of extinct dinosaurs have four-chambered hearts.

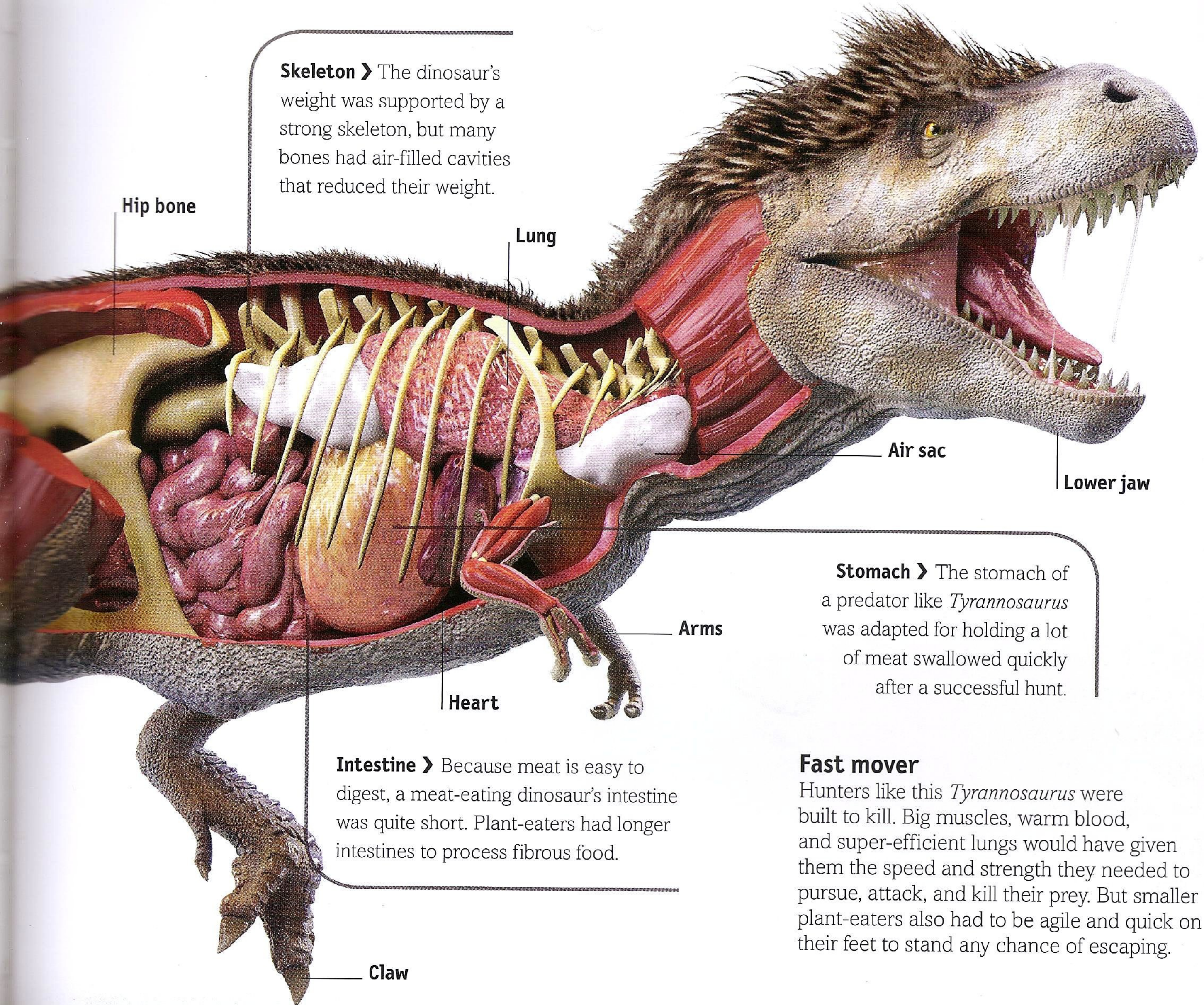


Heart Pumping blood around the body of a giant dinosaur required a powerful four-chambered heart—similar to a bird heart, but a lot bigger.

Air sacs (blue) stored air and pumped it back through the lungs (red).

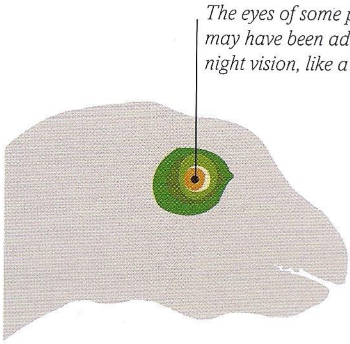


Lungs Fossil evidence shows that dinosaurs had lungs like those of modern birds, which are more efficient than the lungs of mammals.

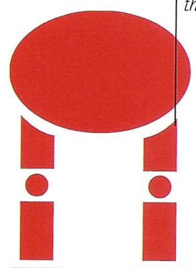


Fast mover

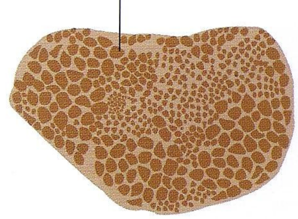
Hunters like this *Tyrannosaurus* were built to kill. Big muscles, warm blood, and super-efficient lungs would have given them the speed and strength they needed to pursue, attack, and kill their prey. But smaller plant-eaters also had to be agile and quick on their feet to stand any chance of escaping.



Vision Their skull anatomy shows that many extinct dinosaurs had sharp senses. Predators like *Tyrannosaurus* would have had excellent vision, which may have been as acute as a modern eagle's.



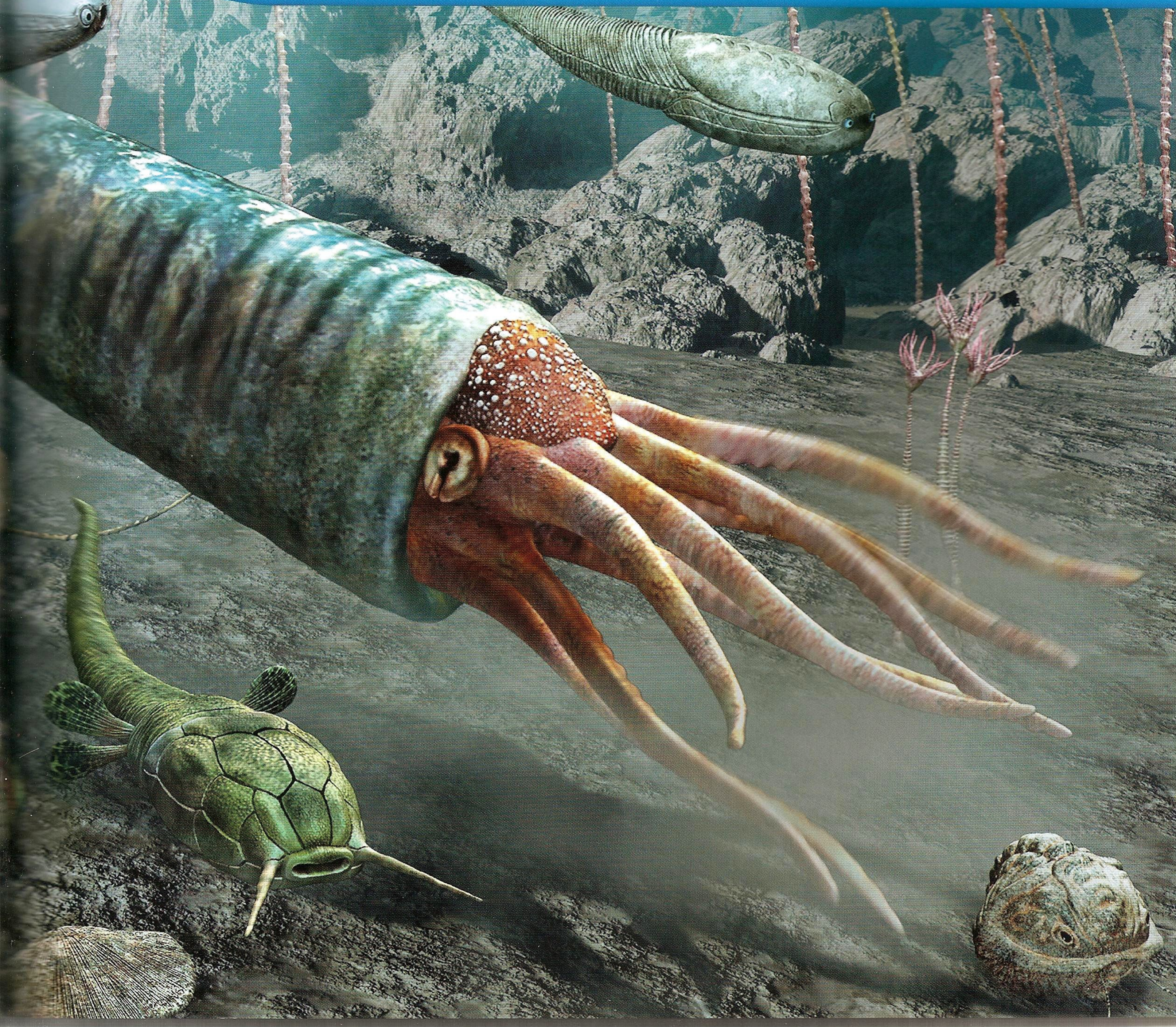
Stance Like birds—but unlike modern reptiles—dinosaurs stood with their legs directly beneath their bodies. This helped to support their weight.



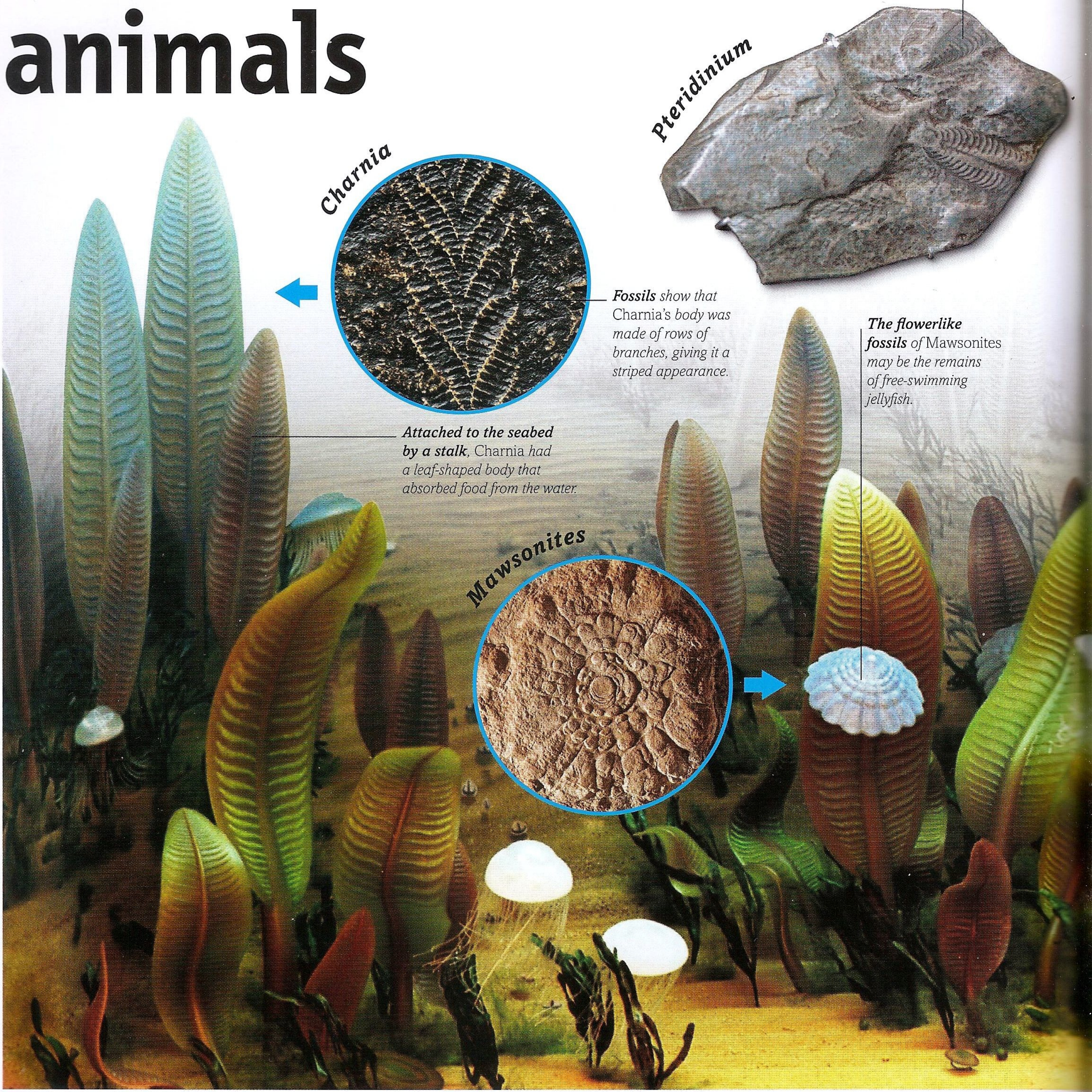
Scales The skins of most big dinosaurs were protected by scales. Many small, feathered dinosaurs also had scales on parts of their bodies.

Feathers Many small theropods and even some big ones were covered in feathers. These kept them warm and allowed some of them to fly.

BEFORE THE DINOSAURS



The first animals

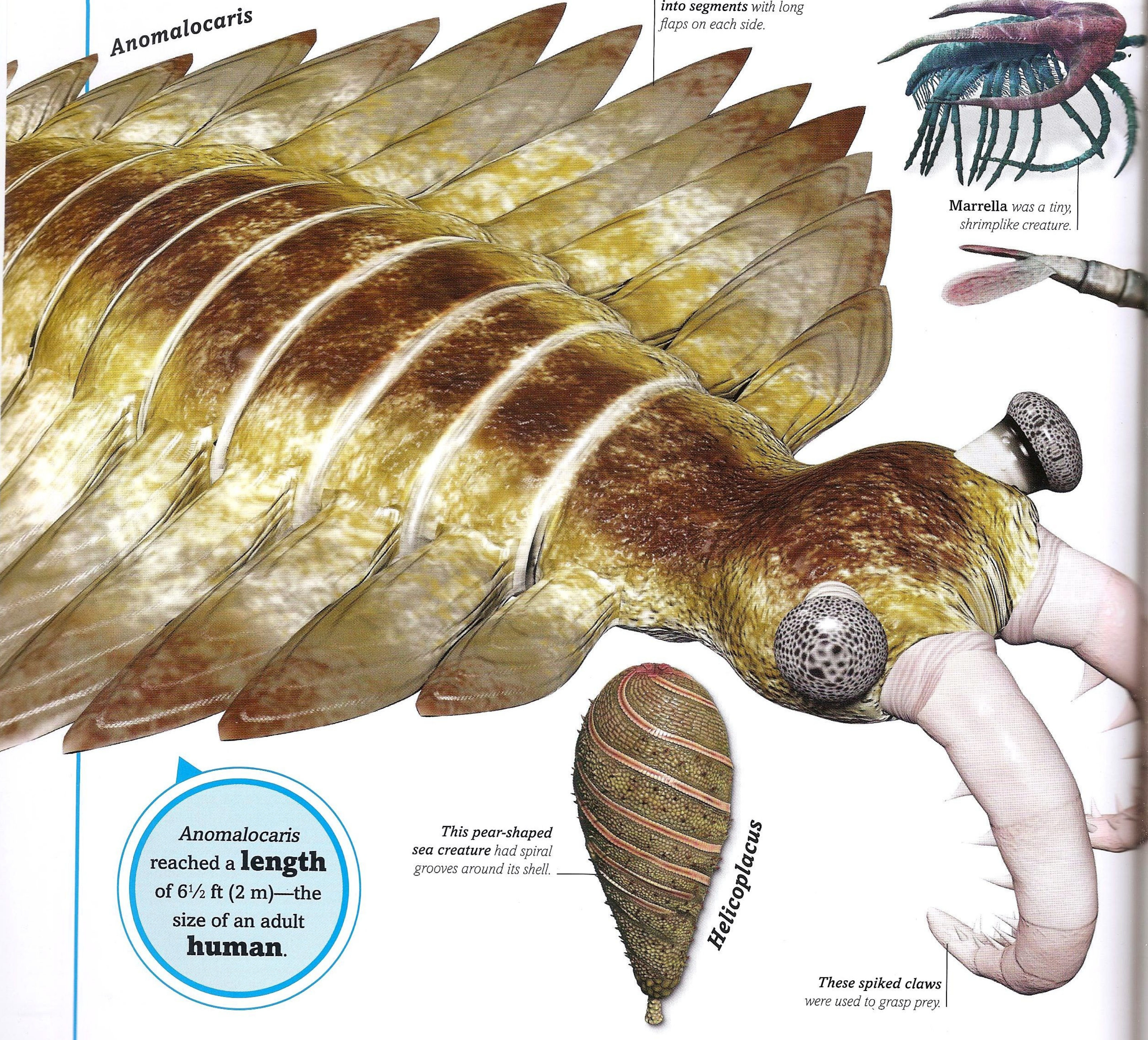


Scientists once thought that the first animals evolved about 542 million years ago at the start of the Cambrian Period. The huge span of Earth history before this, known as the Precambrian Period, was thought to be almost lifeless apart from bacteria and similar microscopic single-celled organisms. But in 1957, a fossil was discovered in the Precambrian rocks of Charnwood Forest in England. It was a multicelled life form, now known as ***Charnia***. Scientists then realized that fossils of similar organisms found in the

The *first known* Precambrian fossil, **Charnia**, was found by a 15-year-old schoolboy.

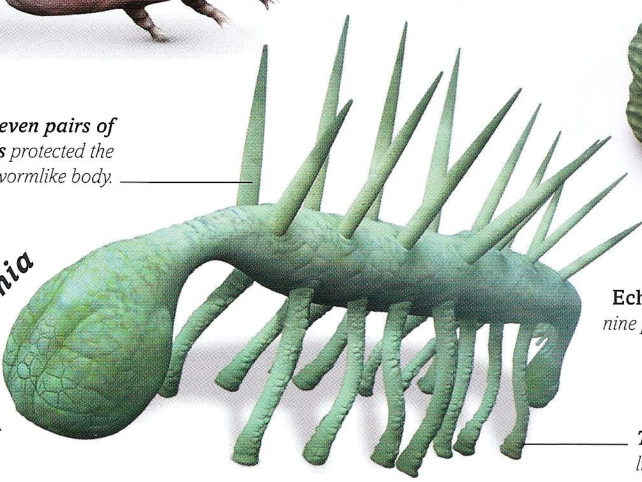
Ediacara Hills of Australia in 1946 were also Precambrian, and more than 600 million years old. These were some of the first animals on Earth. Since then, similar fossils have been found in North America, Africa, and Russia. Many, including *Charnia*, were animals that lived rooted on the seabed, like modern corals. Others, like ***Spriggina***, were free-living animals that could roam or swim in search of food, and some, including ***Dickinsonia***, were so unlike any modern animal that their nature and way of life are still a mystery.

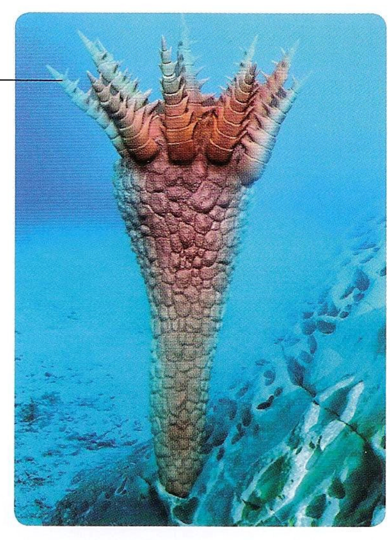
Built to survive



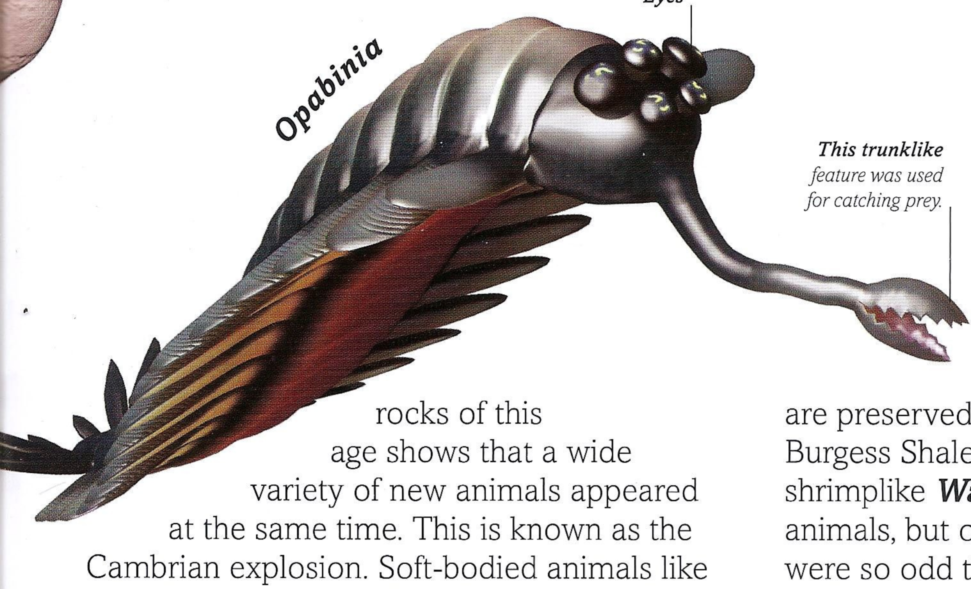
Anomalocaris reached a **length** of 6½ ft (2 m)—the size of an adult **human**.

The earliest animals that lived in ancient oceans had soft bodies, like modern jellyfish. But during the Cambrian Period, from 542 million years ago, new types of animals appeared. They had hard shells, spines, and tough external skeletons, such as those of ***Anomalocaris*** and ***Marrella***. These hard parts supported their bodies and helped protect them from enemies. When the animals died, their soft parts were eaten or rotted, but their shells and skeletons were often preserved as fossils. The appearance of many fossils in





Echmatocrinus



rocks of this age shows that a wide variety of new animals appeared at the same time. This is known as the Cambrian explosion. Soft-bodied animals like the burrowing worm ***Ottoia*** thrived too, and are preserved in rocks such as Canada's Burgess Shale. Creatures like *Ottoia* and the shrimplike ***Waptia*** are similar to modern animals, but others, including ***Opabinia***, were so odd that we are still not sure how they functioned.

SET IN STONE High in the Rocky Mountains of British Columbia, Canada, lies one of the most incredible fossil sites—the Burgess Shale. It was discovered in 1909 by American fossil hunter and scientist Charles Walcott, who realized he had stumbled upon a treasure trove of ancient life. He was to spend much of the next 14 years working on the site, splitting the rock to reveal over 65,000 fossils.

More than 500 million years ago, the Burgess Shale was a muddy seabed at the foot of a coastal cliff. The water teemed with animals, some of which were buried by *mudslides. As the mud turned to rock, their remains were* preserved as flattened fossils, recording the variety of life that had evolved by the start of the Paleozoic Era, about 444 million years ago. Some of the fossils were of animals that had exoskeletons, such as these trilobites, but many more were of soft-bodied animals that were very different *from the creatures we see today, such as the five-eyed Opabinia*. These animals provide scientists with a spectacular snapshot of life millions of years ago.

Trilobites

Paradoxides *was one of the earliest and biggest trilobites, growing to 15 in (37 cm) long.*

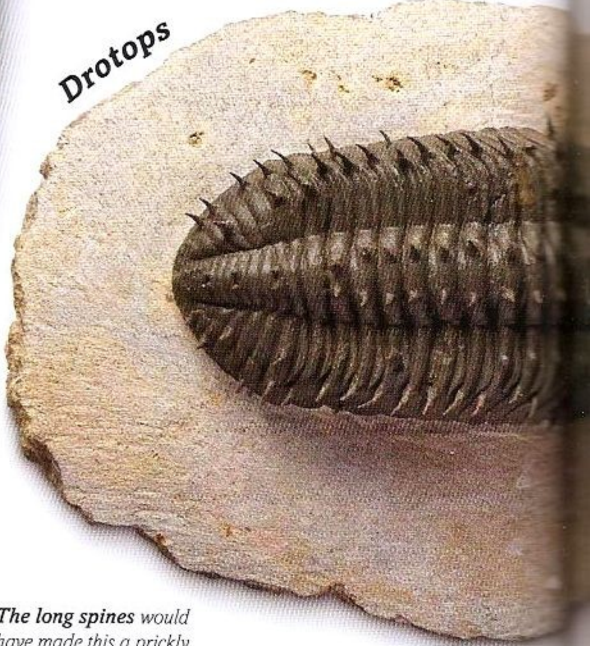
Paradoxides

Phacops *had a pair of compound eyes, each made up of many small lenses.*

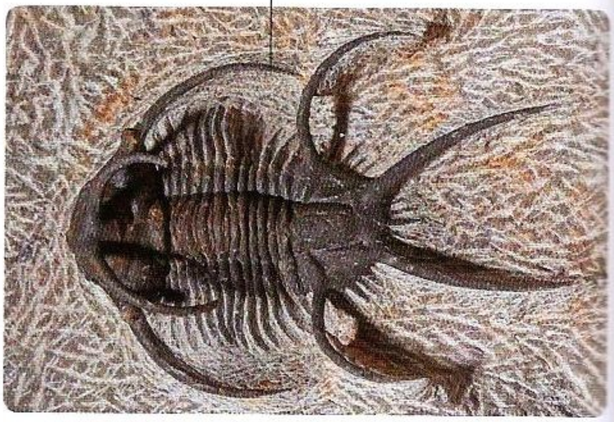
Curled Phacops

***The armored body curled up** into a ball to protect its soft underside from attack.*

Drotops



***The long spines** would have made this a prickly mouthful for a predator.*



Ceratalges

Trilobites, with their segmented bodies, are among the most distinctive fossils found in ancient rocks. The earliest trilobites appear in rocks that are more than 520 million years old. They thrived in the oceans for an amazing 270 million years until the catastrophic mass extinction that ended the Paleozoic Era 252 million years ago. Trilobites were some of the earliest arthropods—animals with external skeletons and jointed legs, like today's insects and spiders. Many trilobites like ***Drotops*** looked like flattened pillbugs, with several pairs of legs

Uncurled Phacops

The body of Phacops *was made up of 11 segments, each bearing a pair of legs.*

Walliserops

The three-pronged spear may have been used to fight rivals.

The dome-shaped, bumpy head shield covered the trilobite's mouthparts.

Ditomopyge

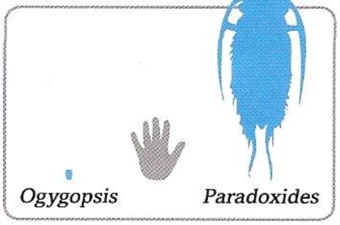
Like many trilobites, this was probably a seabed hunter and scavenger.

Selenopeltis

These fossils may be the empty skins of Selenopeltis*—all trilobites shed their skins as they grew.*

Ogygopsis

This was one of the most common trilobites found in Burgess Shale, Canada.



Xystridura

The tail was made up of many segments fused into a single plate.

and large eyes; trilobites were among the first animals to evolve compound eyes packed full of lenses, just like those of today's insects. Some, including ***Ceratalges*** and ***Walliserops***, had spectacular spines that may have been for courtship or defense. Many would have foraged for food on the seabed, but others could swim. There were at least 17,000 known species, ranging from tiny creatures less than ⅛ in (3 mm) long to animals that were as big as this book.

The age of fish

All land vertebrates, including dinosaurs, are descended from fish—the first animals to have backbones. Fish evolved from soft-bodied creatures like ***Pikaia***, which lived over 500 million years ago. Early forms like ***Astraspis*** had a soft, jawless mouth and a flexible rod called a notochord in place of a bony spine. Over the next 100 million years, fish developed hinged jaws and backbones. During the Devonian Period, 416–358 million years ago, they became so successful that this period is known as the age of fish. Two main groups

Unlike modern ***sharks****, the mouth was at the tip of the snout rather than on the underside.*

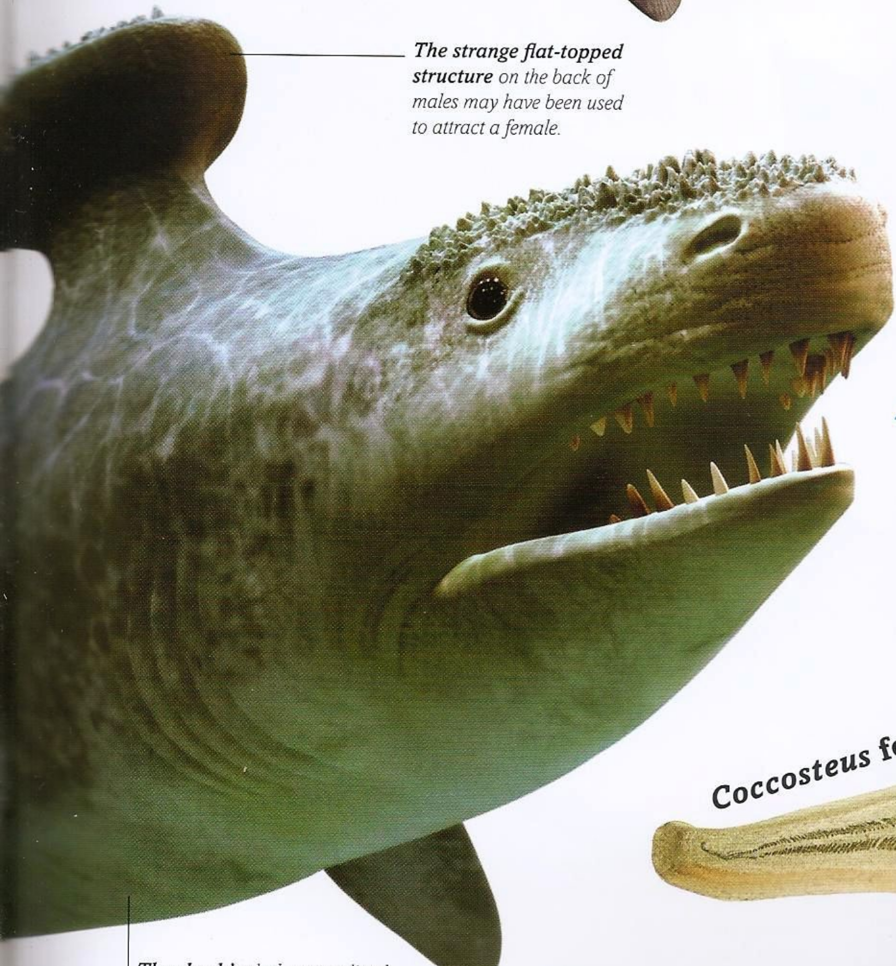
Cladoselache

Pikaia

Pikaia *was a primitive chordate—an animal with a spinal cord but no bones.*

A long, flat body extended from behind Pikaia's small head.

The strange flat-topped structure *on the back of males may have been used to attract a female.*



Stethacanthus had **many tooth-like scales** on its head and dorsal fin.

The shark's sleek, streamlined body was adapted for fast movement through the water.

This armored fish *had a bony head shield.*

Coccosteus fossil

Large scales *covered the body of this lobe-finned fish.*

Holoptychius

The paired fins *under the body contained strong limb bones.*

evolved—sharks like ***Stethacanthus*** and ***Cladoselache*** had skeletons made of a rubbery material called cartilage, while the so-called bony fish like ***Cheirolepis*** had skeletons of hardened bone. Some of these fish also had four stout, bony fins beneath their bodies. Called the lobe-finned fish, they were the first vertebrates to crawl out of the water and live on land. Fish have continued to flourish ever since; even though the largest mass extinction wiped out 90 percent of marine species 251 million years ago, fish managed to survive.

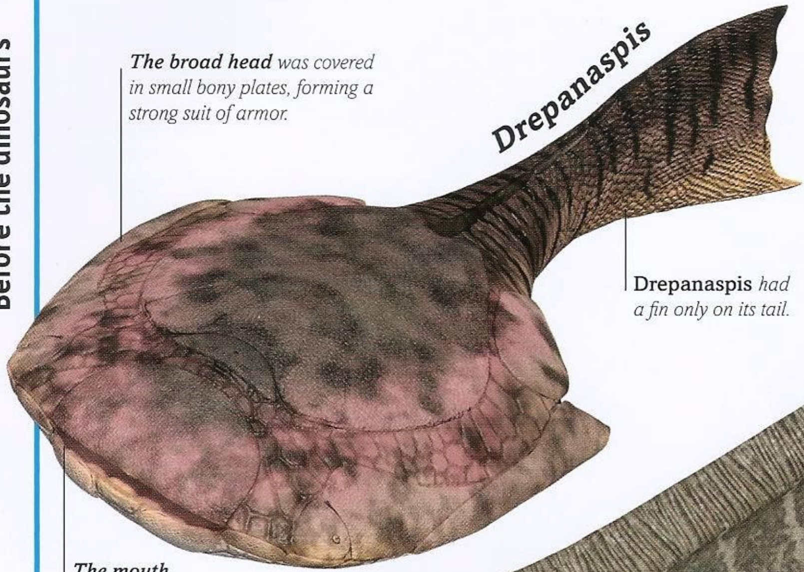
Fish armor

The back of this early jawless fish was protected by bony scales.

Birkenia

The broad head was covered in small bony plates, forming a strong suit of armor.

Drepanaspis



Drepanaspis *had a fin only on its tail.*

The mouth pointed upward.

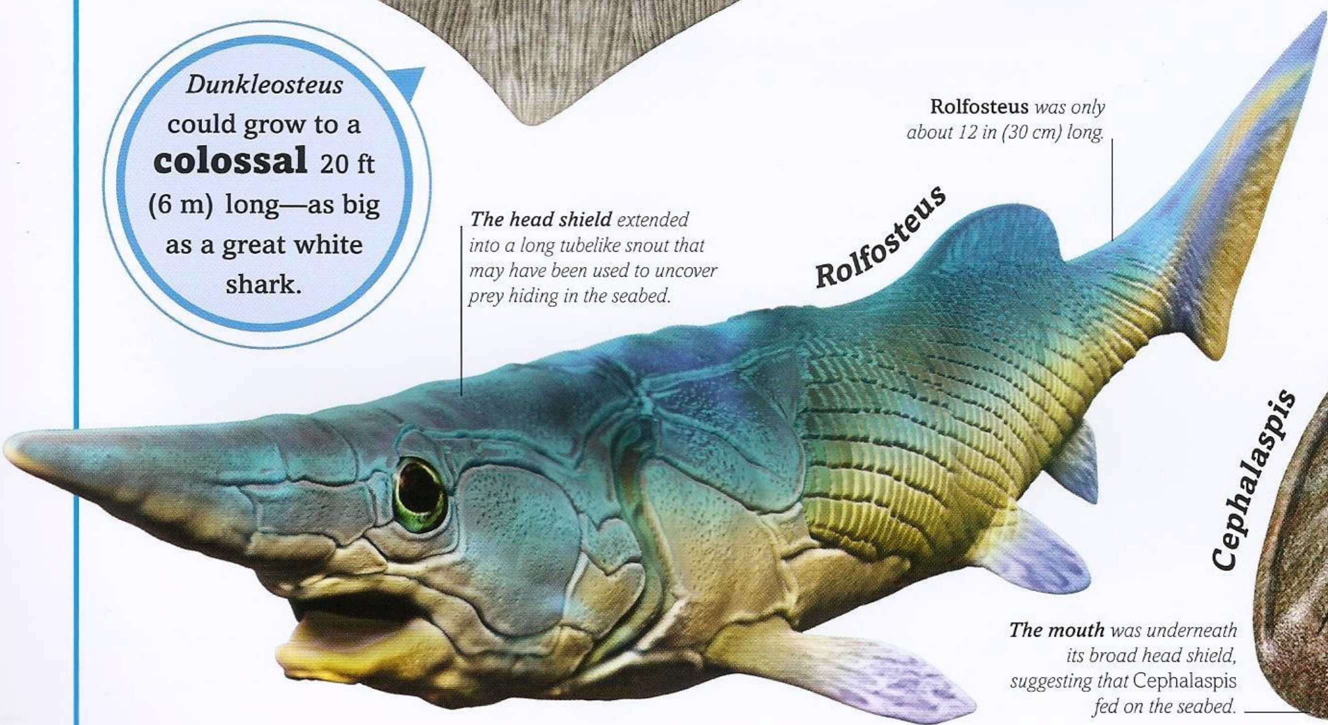
Most of the body was not armored, allowing flexibility for swimming.

Dunkleosteus could grow to a **colossal** 20 ft (6 m) long—as big as a great white shark.

Rolfosteus *was only about 12 in (30 cm) long.*

The head shield extended into a long tubelike snout that may have been used to uncover prey hiding in the seabed.

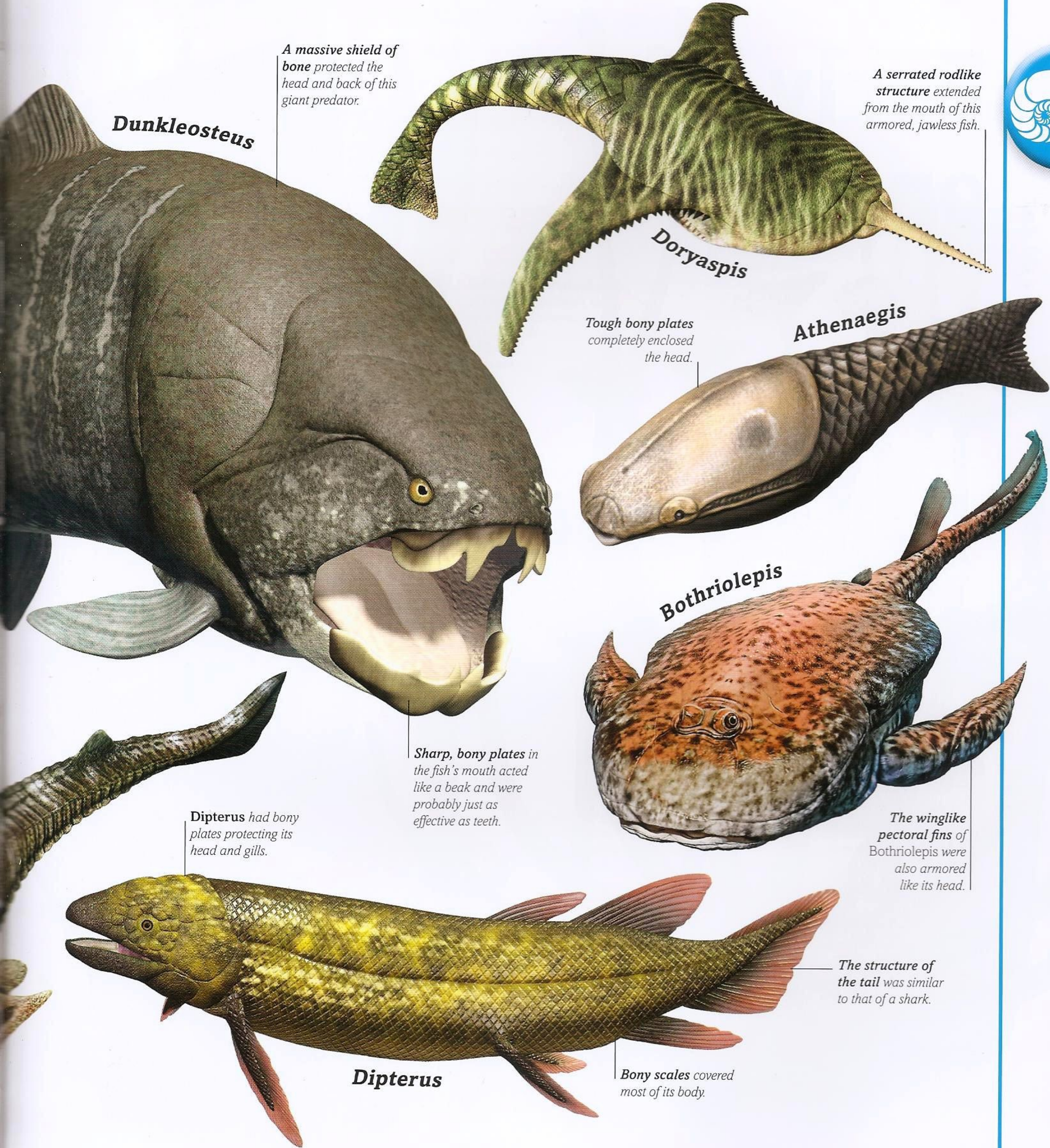
Rolfosteus



Cephalaspis

The mouth was underneath its broad head shield, suggesting that Cephalaspis fed on the seabed.

Many early fish had tough armor protecting their heads, and sometimes their bodies too. The first of these armored fish appeared more than 400 million years ago. The jawless ***Cephalaspis*** and ***Drepanaspis*** had big horseshoe-shaped head shields. They were much smaller than the armored, jawed fish that evolved later—the placoderms. Some of these massive jawed fish were monstrous looking. Their heads and upper bodies were covered with tough, overlapping plates of bone that were hinged to allow movement. The armor



may have provided defense against predators. The only animals that might threaten them were sharks and other big, fish-eating predators, since the fearsome marine reptiles with their powerful jaws did not appear in the oceans for another 100 million years. Some of the placoderms, like the great white shark–sized ***Dunkleosteus***, would have had few enemies—it had one of the most powerful bites of any fish and bony plates that were about 2 in (5 cm) thick. It is also likely that they were armored as defense against each other.

Early life on land

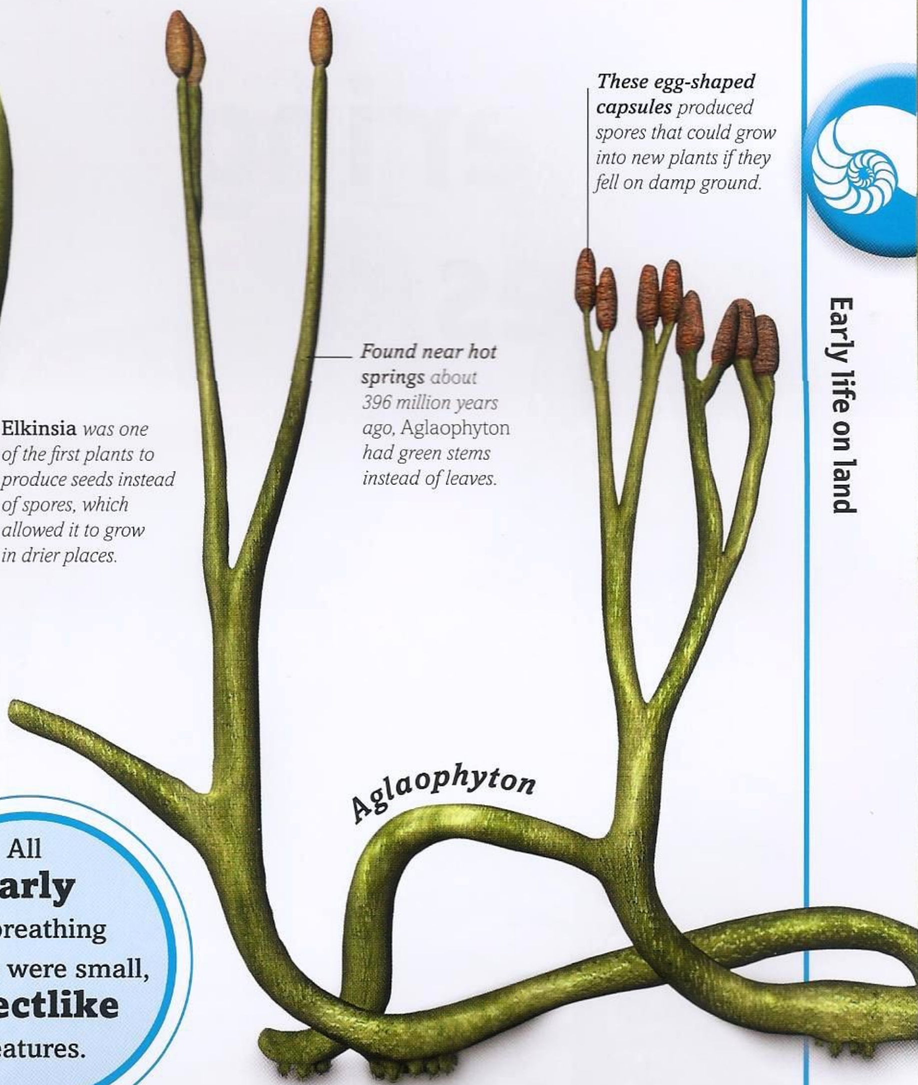
Until about 500 million years ago, there was no life on land. The continents were barren rock and sand like the surface of Mars. The first land organisms were probably microscopic bacteria that built up in mats. These were followed by fungi that lived off the bacterial mats and broke them down to form soil, allowing early plants to get a root-hold. Spores of these plants have been found in fossils that formed about 476 million years ago. The plants would have looked like ***Aglaophyton*** and ***Sciadophyton***—simple, mosslike plants that grew close to the

Elkinsia

Seeds *were held within these structures.*

Elkinsia *was one of the first plants to produce seeds instead of spores, which allowed it to grow in drier places.*

These veins *carried water and sap through the plant.*



Aglaophyton

These egg-shaped capsules *produced spores that could grow into new plants if they fell on damp ground.*

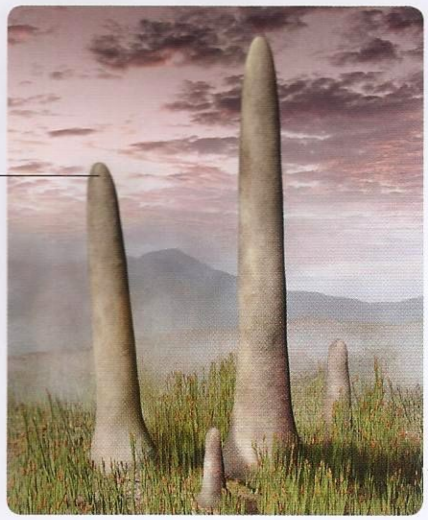
Found near hot springs *about 396 million years ago,* Aglaophyton *had green stems instead of leaves.*

All **early** air-breathing animals were small, **insectlike** creatures.

Palaeocharinus

Palaeocharinus ***had eight jointed legs*** *and a pair of long sensory palps, like most modern spiders.*

Growing to 26 ft (8 m) high, Prototaxites *would have dominated the landscape 415 million years ago.*



Prototaxites

ground in damp places. Over time, plants evolved veins that allowed water and sap to flow through stems connecting their roots and leaves. This allowed them to grow taller, eventually leading to trees like the 20-ft- (6-m-) high ***Archaeopteris***—the first tree to have dense wood and true leaves and to form large forests. Meanwhile, the fungi, bacteria, and plants provided food for early land animals like the millipede *Pneumodesmus*. These small animals were in turn hunted by predators, including the spiderlike ***Palaeocharinus***.

Towering trees

Macroneuropteris

This fossilized leaflet *had a heart-shaped base.*

Walchia

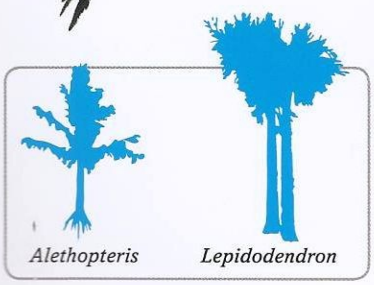
This early conifer *had a tall, straight trunk and short, needle-shaped leaves.*

Lepidodendron

The bark *of this giant clubmoss had a distinctive diamond pattern.*

Alethopteris

Despite its fernlike leaves, Alethopteris *produced seeds instead of spores.*



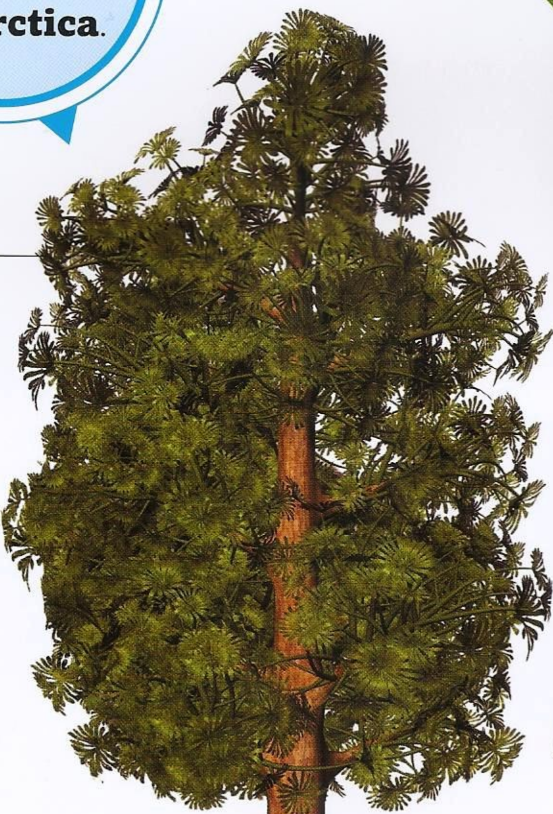
Although known as the age of fish, the Devonian Period also saw the transformation of land habitats by plant life. The first woody trees appeared in the late Devonian, about 385 million years ago, and spread to form the earliest forests. During the next 85 million years, throughout the Carboniferous Period, trees and other plants colonized the land and created habitats for animal life. Many of these plants grew in swamps, and when they died, their remains formed peat that ultimately turned to coal. Some trees, such

Ferns *like* Paripteris *were some of the first plants to evolve seeds.*

Shed leaves *left scars that formed a honeycomblike pattern on the bark.*

This primitive plant *resembled a tree fern.*

Glossopteris once formed **lush forests** on the continent of **Antarctica**.

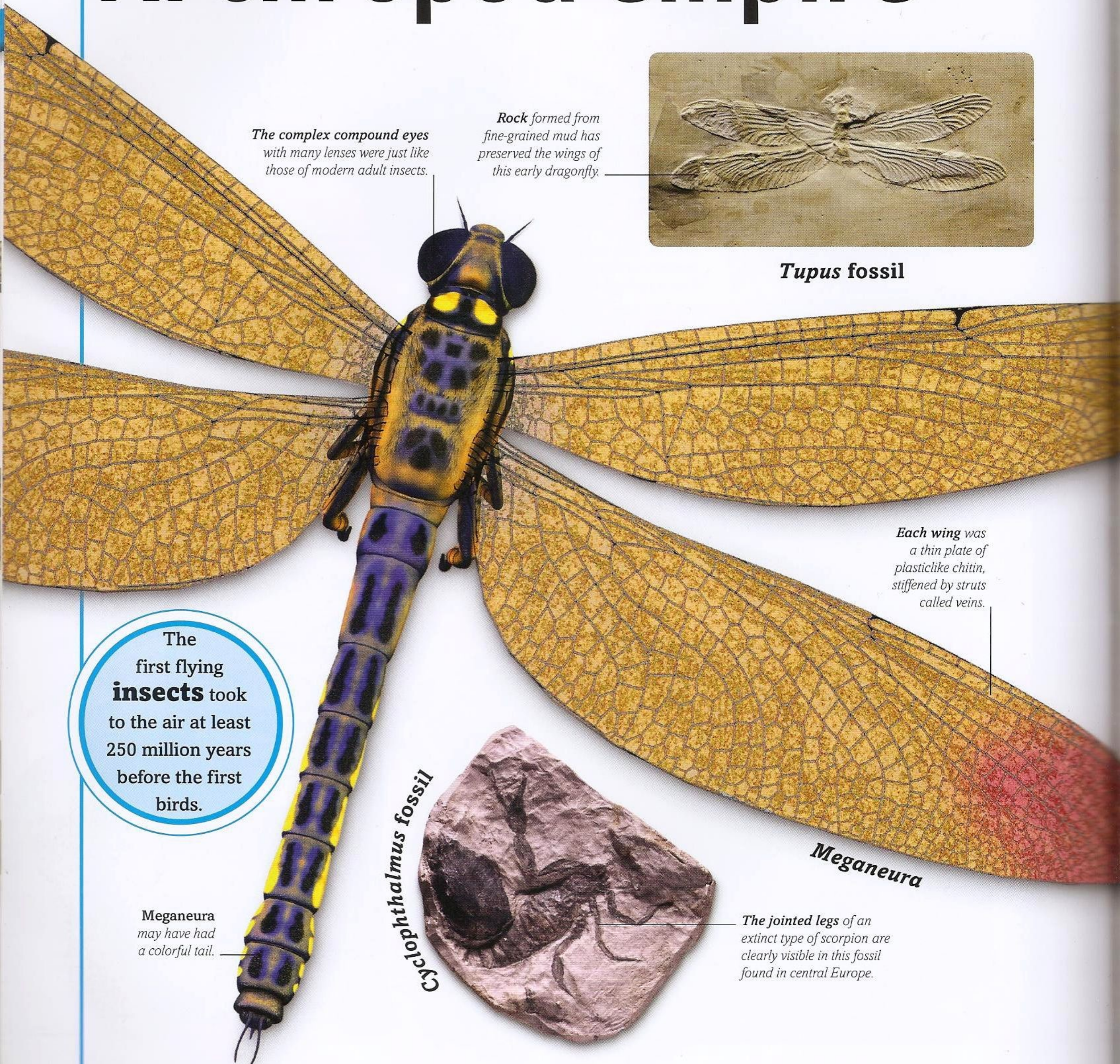


Glossopteris *means* ***"tongue fern,"*** *describing its leaf shape.*

The fossilized leaves *were very like modern fern fronds.*

as ***Sigillaria*** and ***Lepidodendron***, looked similar to modern trees but were clubmosses—relatives of mosses and ferns. These could grow to great heights—*Lepidodendron* towered 130 ft (40 m) or more. Many plants resembled modern spore-bearing ferns and horsetails, but others, including ***Alethopteris*** and ***Paripteris***, bore true seeds. By the late Carboniferous, plants like ***Walchia*** had evolved—the first of the pinelike conifer trees that later became an important food source for dinosaurs.

Arthropod empire



The complex compound eyes with many lenses were just like those of modern adult insects.

Rock *formed from fine-grained mud has preserved the wings of this early dragonfly.*

Tupus **fossil**

Each wing *was a thin plate of plasticlike chitin, stiffened by struts called veins.*

The first flying **insects** took to the air at least 250 million years before the first birds.

Meganeura *may have had a colorful tail.*

Meganeura

Cyclophthalmus **fossil**

The jointed legs *of an extinct type of scorpion are clearly visible in this fossil found in central Europe.*

Forests of towering trees and other plants spread over the land from about 358–299 million years ago, providing food for many small plant-eating animals. They included soft-bodied animals like worms, whose burrows have been found fossilized. But most of the fossilized land animals of this period were arthropods—creatures with tough external skeletons and jointed legs, like today's insects, spiders and crustaceans. They included early millipedes like ***Euphoberia***, and plant-eating insects like ***Archimylacris***—a type of

Millipedes like Euphoberia *were some of the first animals to live entirely on dry land.*

***Euphoberia* fossil**

This 310-million-year-old insect *used its piercing mouthparts to suck plant sap.*

***Like all early flying insects,* Stenodictya** *flew on two pairs of wings like those of dragonflies.*

Stenodictya

The long, slender pincers *of this scorpion are very like those of the more venomous modern scorpions.*

***Gallio* fossil**

The long tail *was probably tipped with a powerful stinger for defense and killing prey.*

***Archimylacris* fossil**

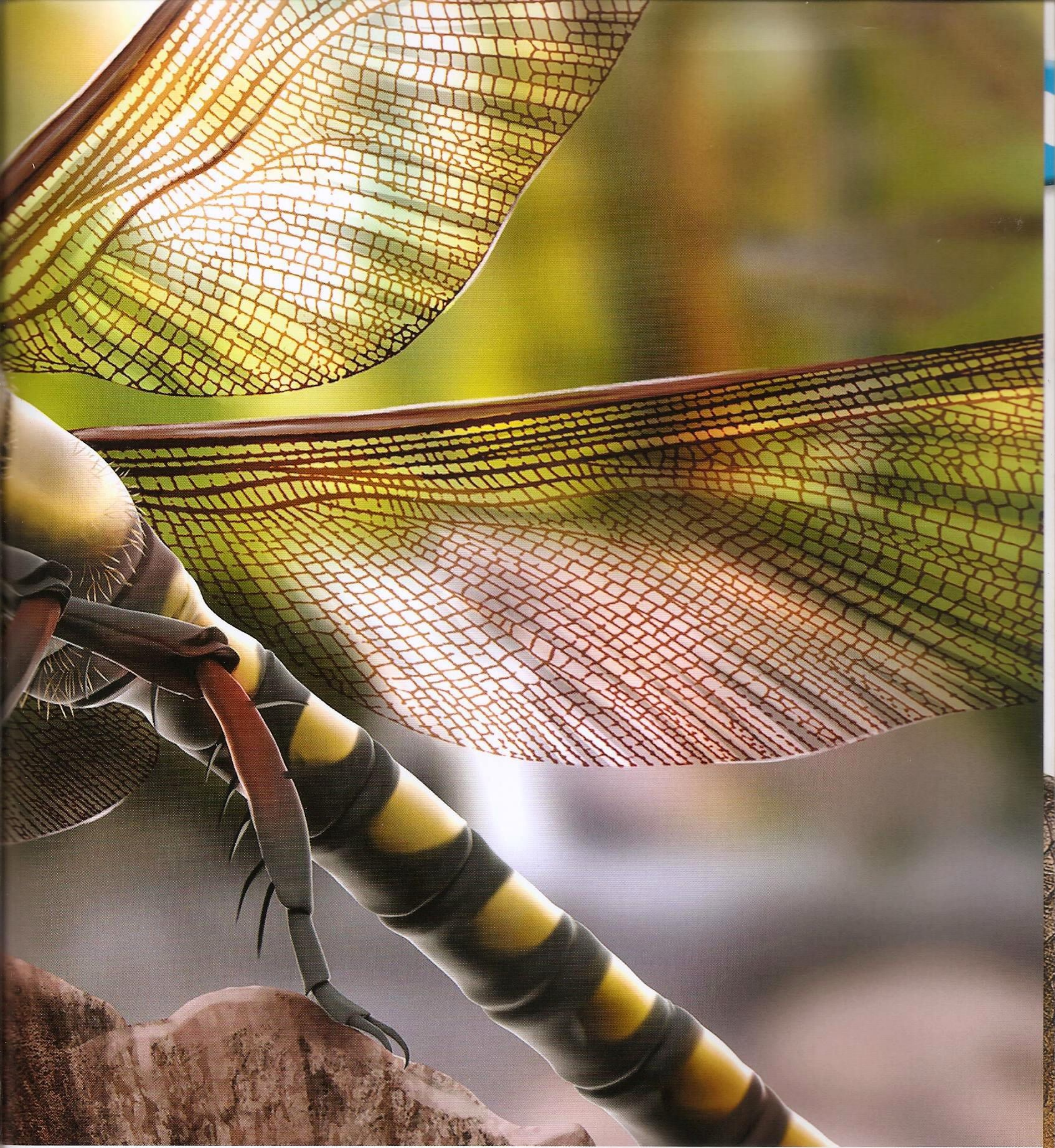
Living 300 million years ago, *this cockroach would have fed on decaying plant material on the forest floor.*

A beautifully preserved fossil *reveals dark bands on the wings of* Lithomantis.

***Lithomantis* fossil**

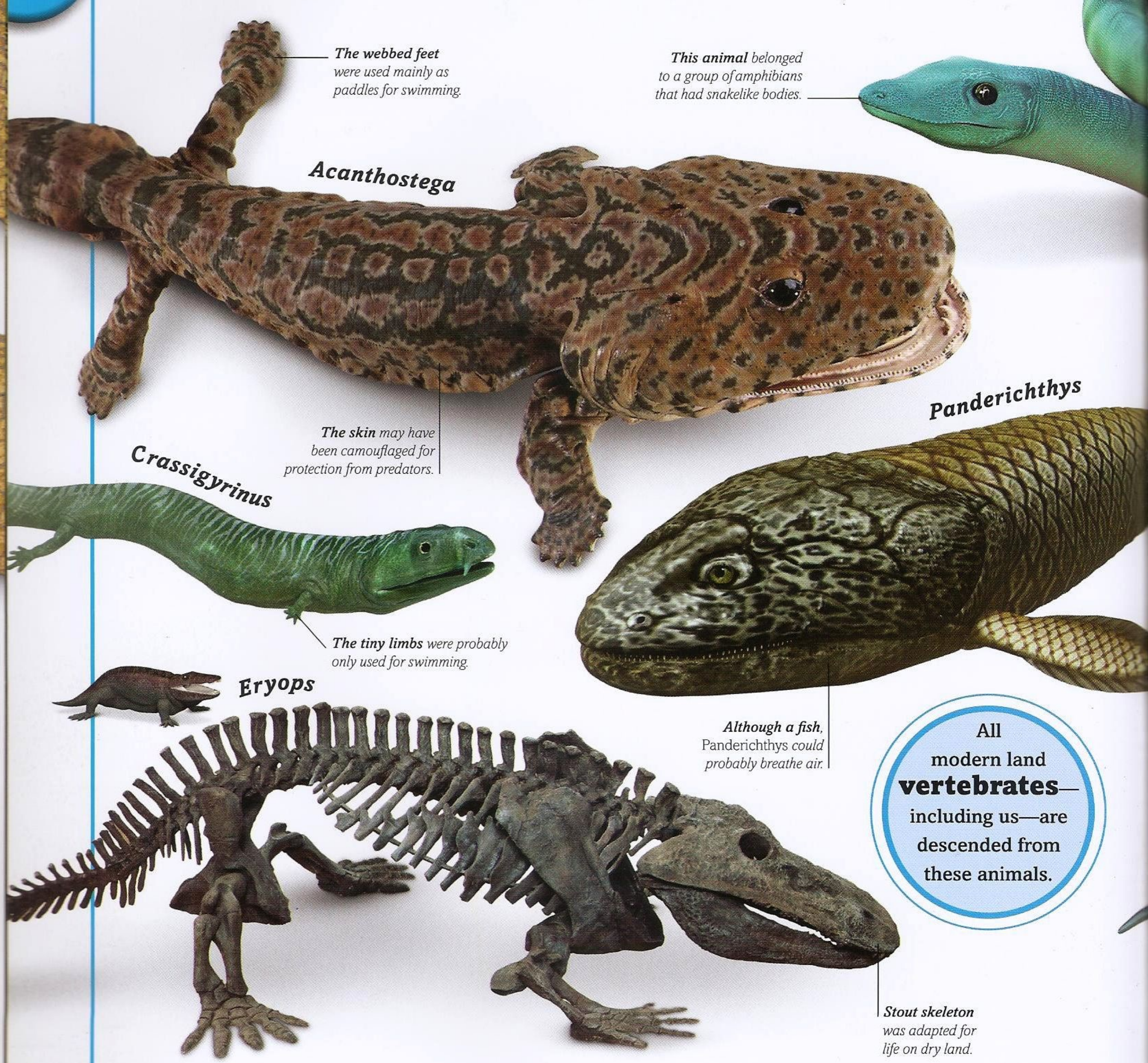
cockroach. They were hunted by predatory centipedes, early spiders, scorpions like ***Cyclophthalmus***, and insects like ***Meganeura***. The forests would have been buzzing with these animals, especially insects that, in an era before birds, were the only animals able to fly. Many would have spent most of their lives as wingless nymphs or grubs that lived underwater or in the ground, before emerging as winged adults. Like modern mayflies, these may have had very short adult lives, but they have survived for millions of years as fossils.

AIRBORNE GIANT Some of the most spectacular insects that ever lived flew through the lush forests of the Carboniferous Period, about 300 million years ago. They were griffinflies—extinct relatives of modern dragonflies, but far bigger. Fossils of the largest known dragonfly relative, *Meganeura*, show that its wingspan reached more than 27 in (69 cm), almost four times the size of the biggest living dragonflies.

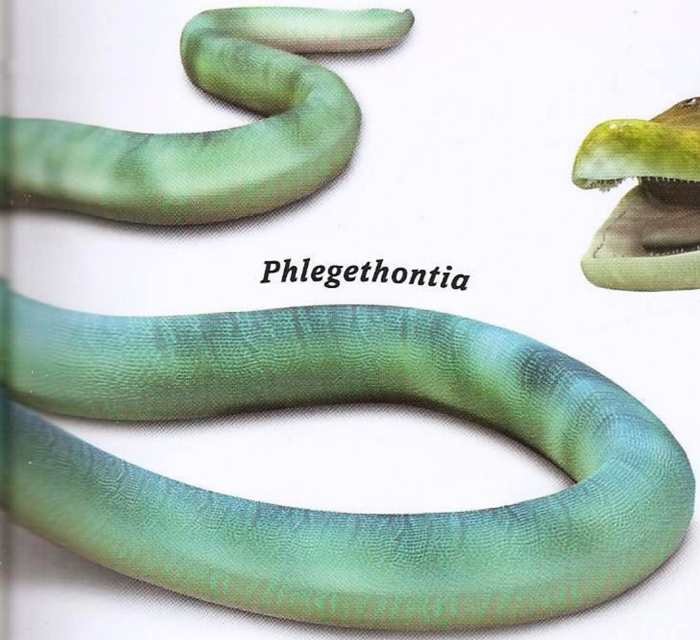


Like its modern counterparts, *Meganeura* was a hunter that preyed on other insects. It probably used the same predatory technique, targeting airborne prey and seizing them with its bristly legs. Flying back to a perch, *Meganeura* would then use its powerful biting jaws to chew through its prey's tough armor to reach the soft flesh within. *Meganeura* would have laid its eggs in water, and after these hatched, the young would live underwater for several years before emerging to change into adult flying insects. The puzzle about *Meganeura* is how it could grow so much bigger than any living dragonfly. One theory is that higher oxygen levels in the atmosphere allowed insects to grow larger than they do now.

Early amphibians



The first four-legged animals on land were amphibians, much like our modern frogs and salamanders. Their ancestors were Devonian fish like ***Panderichthys*** and ***Eusthenopteron***, which had unusually stout bones supporting the four fins beneath their bodies. Some of these fish, the immediate ancestors of tetrapods, evolved to survive out of the water by using their lungs and mouths for breathing. ***Acanthostega*** and ***Tiktaalik*** may have lived at least partly on land. By about 358 million years ago, amphibians



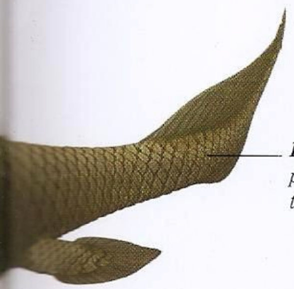
Phlegethontia

Tiktaalik

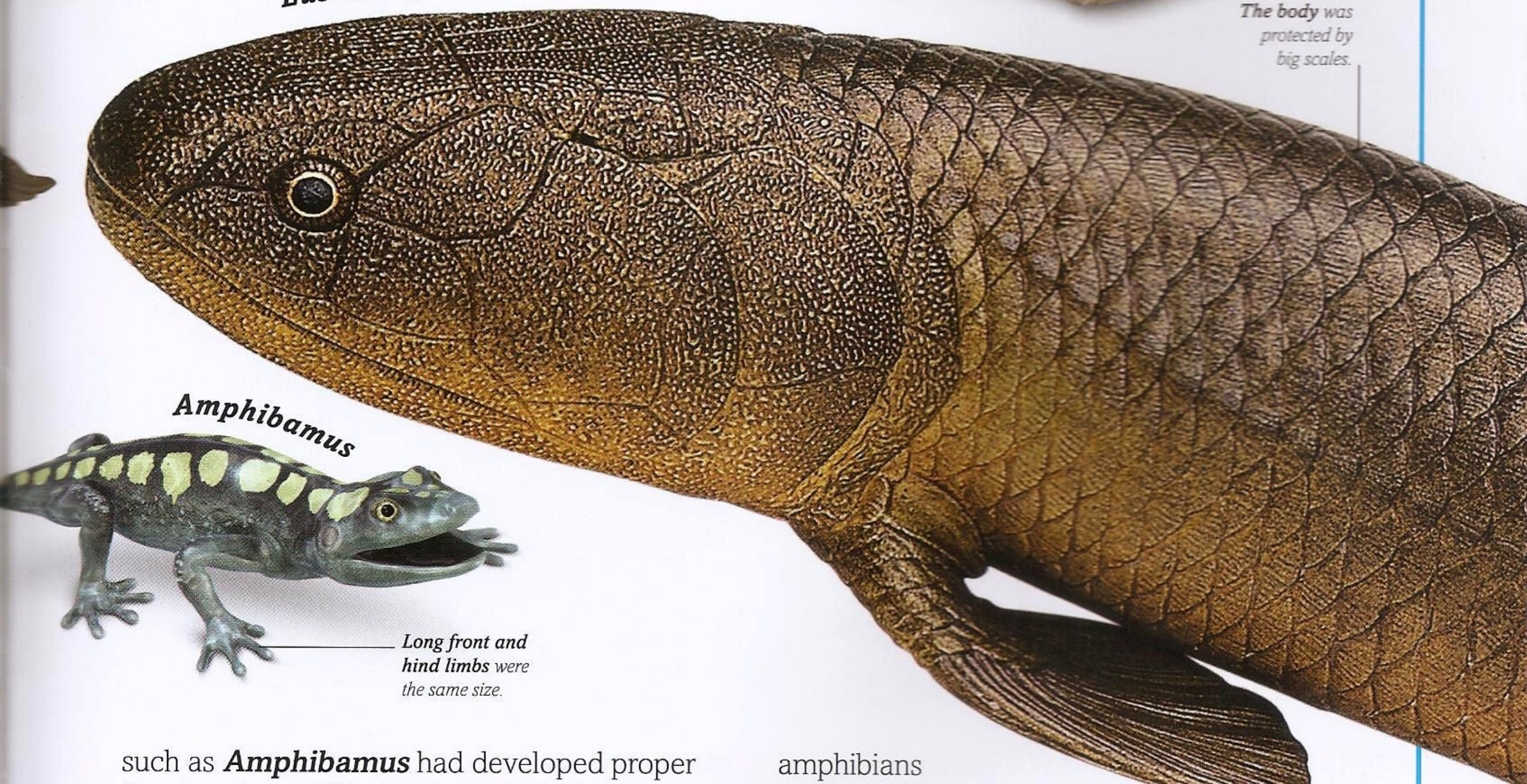
The strong bony fins *were to evolve into legs.*

Seymouria fossil

Seymouria's ***skull*** *was unusually thick and strong.*



Powerful tail *propelled this fish through water.*



Eusthenopteron

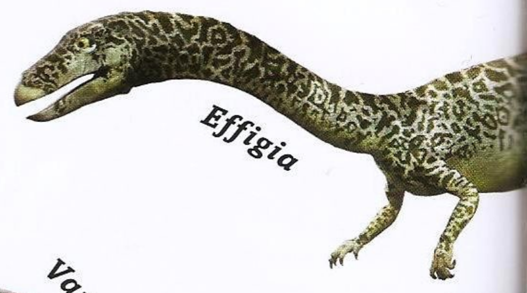
The body *was protected by big scales.*

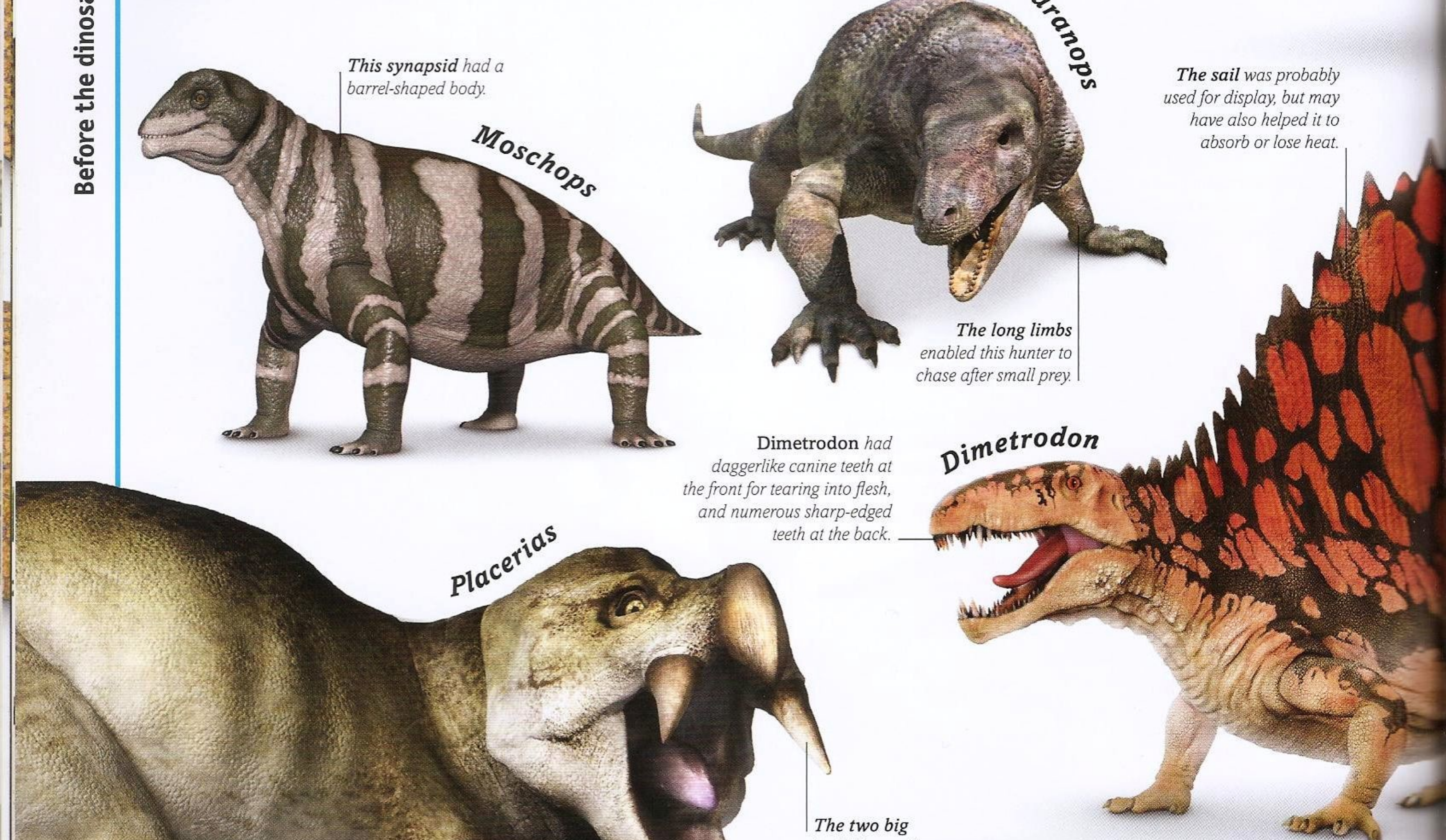
Amphibamus

Long front and hind limbs *were the same size.*

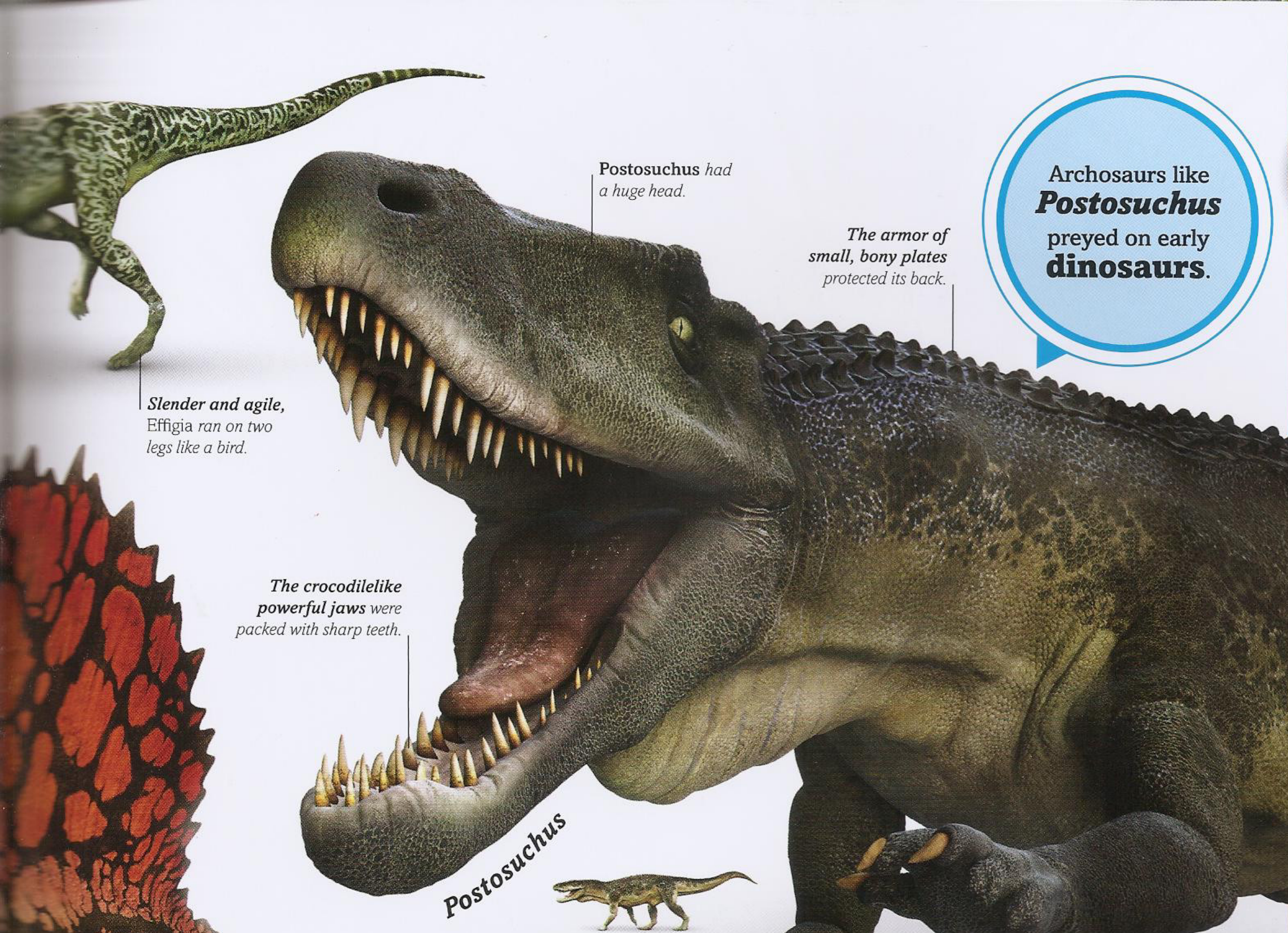
such as ***Amphibamus*** had developed proper feet, but they still had to keep their skin moist to survive. They also had to return to the water to lay their eggs, because the eggs of all amphibians are like those of fish, and dry up if they are not laid in wet places. Eventually, amphibians similar to ***Eryops*** and ***Seymouria*** evolved into a group of animals that were better adapted to live on dry land—the first reptiles.

Reptiles branch out





Long before the first dinosaurs, about 320 million years ago, some reptiles evolved into animals known as synapsids—they would eventually give rise to the mammals. The earliest of these animals—***Ophiacodon*** and ***Varanops***—had sprawling lizardlike limbs. Some, including the predatory ***Dimetrodon*** and plant-eating ***Edaphosaurus***, had huge "sails" on their backs supported by rodlike spine bones. Later, about 299 million years ago, these reptilelike animals gave rise to a group of animals called dicynodonts—***Placerias***



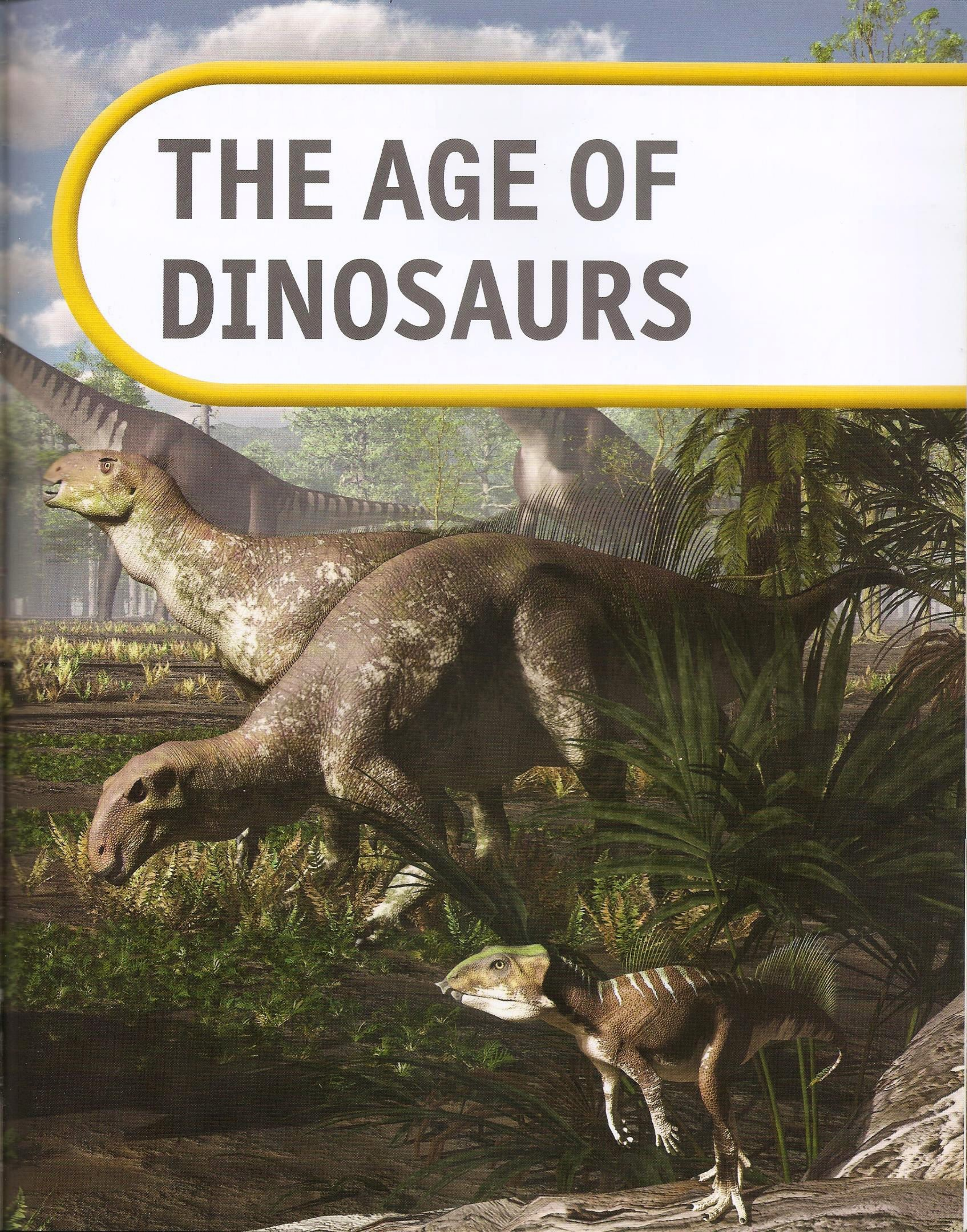
was among the largest of these animals. A few similar animals survived the catastrophic mass extinction at the end of the Permian and evolved into cynodonts, which became the ancestors of modern mammals. Meanwhile, the reptile line had given rise to archosaurs—the group of animals that eventually included crocodylians, pterosaurs, dinosaurs, and birds. Some of the more powerful Triassic archosaurs, like ***Postosuchus***, were the top predators of their time. Others, including ***Effigia***, were very similar to the first dinosaurs.

HUNGRY HUNTER

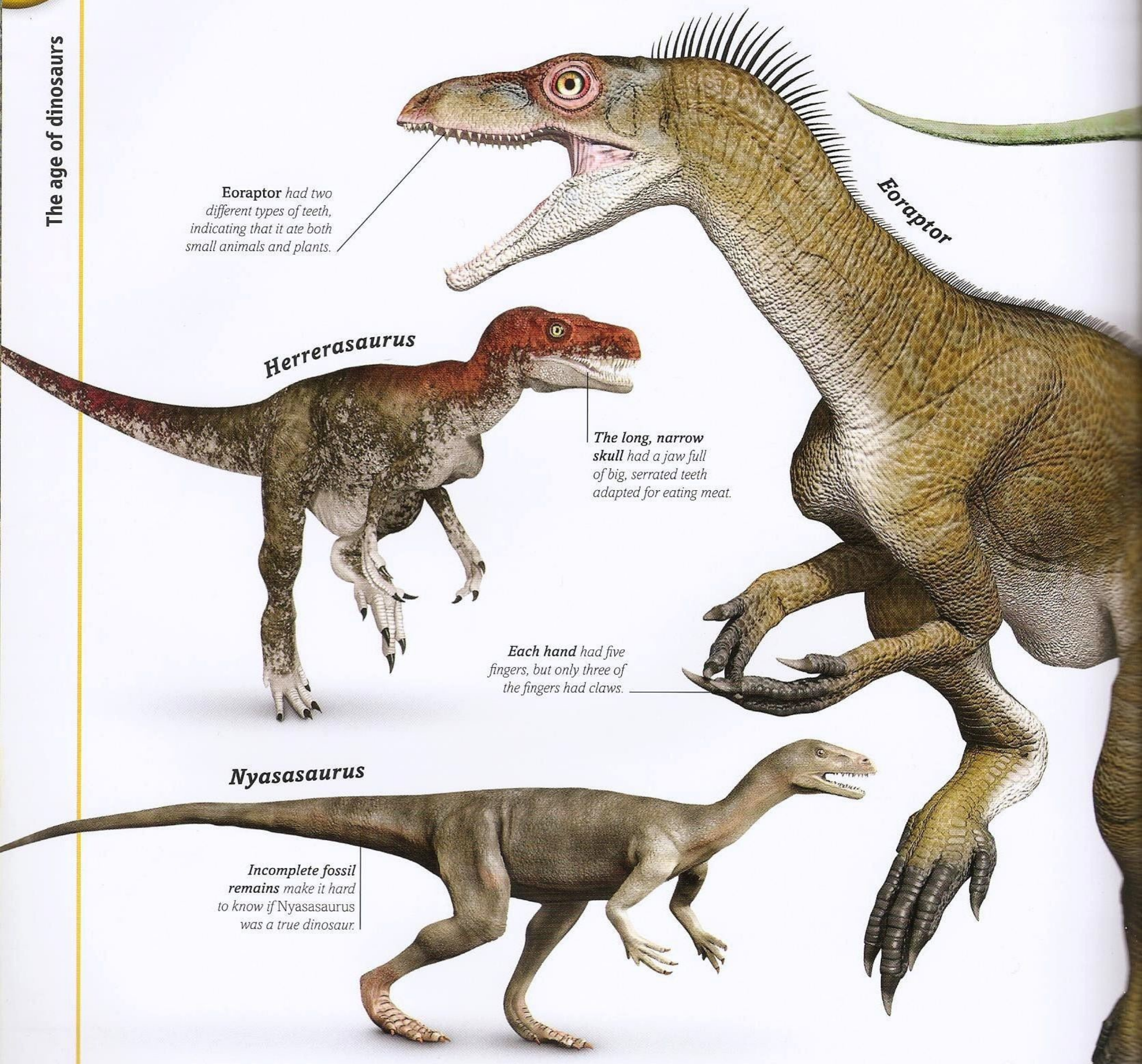
Concealed by its camouflaged scaly skin, which closely matches the surrounding ferns, a hungry, sail-backed *Arizonasaurus* stalks a herd of plant-eating dicynodonts—relatives of mammals. Reptiles like *Arizonasaurus* were the main threat to plant-eaters in the mid-Triassic Period, before the evolution of big predatory dinosaurs.

The first dinosaurs evolved during the Triassic Period, but they were not the giant, ruling reptiles that we are familiar with. The Triassic world was ruled by reptiles of a different type—animals like *Arizonasaurus*. They were archosaurs, as were the dinosaurs, but had evolved along different lines to resemble high-walking crocodiles. Many had massive jaws and teeth and were capable of overpowering and eating any animal they might encounter. *Arizonasaurus* belonged to a group of archosaurs that had tall "sails" on their backs, supported by bones extending up from the spine. The function of the sail is uncertain, but it may have been important during displays to rival animals of the same species.

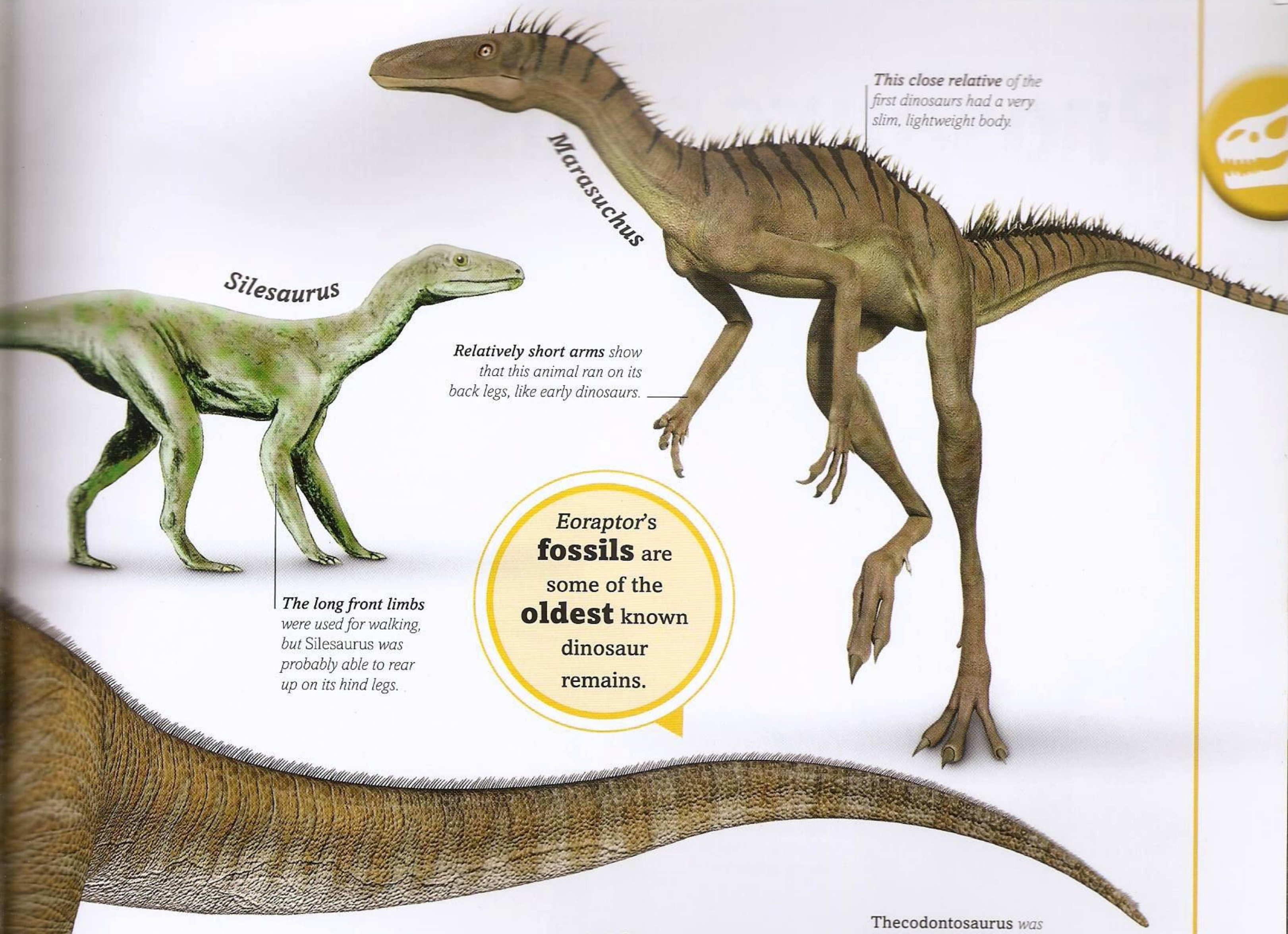
THE AGE OF DINOSAURS



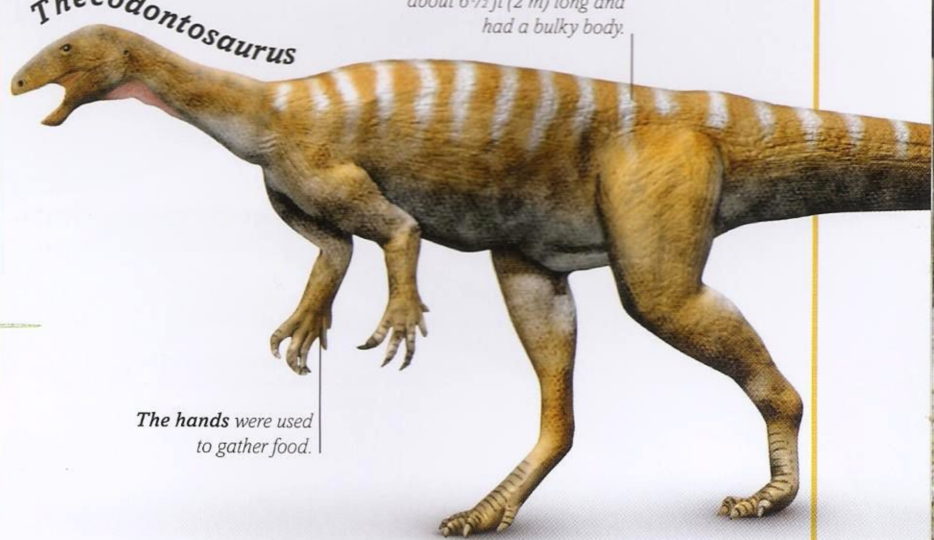
The first dinosaurs



Although dinosaurs evolved into some of the biggest and most spectacular land animals the world has seen, they had small beginnings. About 240 million years ago, in the early Triassic, the largest reptiles were powerful, crocodilelike archosaurs. These had some smaller archosaur relatives with slender bodies and long legs, such as ***Marasuchus***, which was just 28 in (70 cm) long and chased after small prey on its hind legs. The bigger, slightly more dinosaurlike ***Silesaurus*** had a similar build, but seems to have eaten plants,

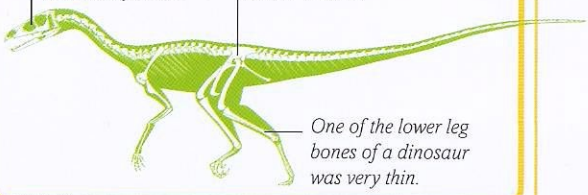


Eoraptor's **fossils** are some of the **oldest** known dinosaur remains.



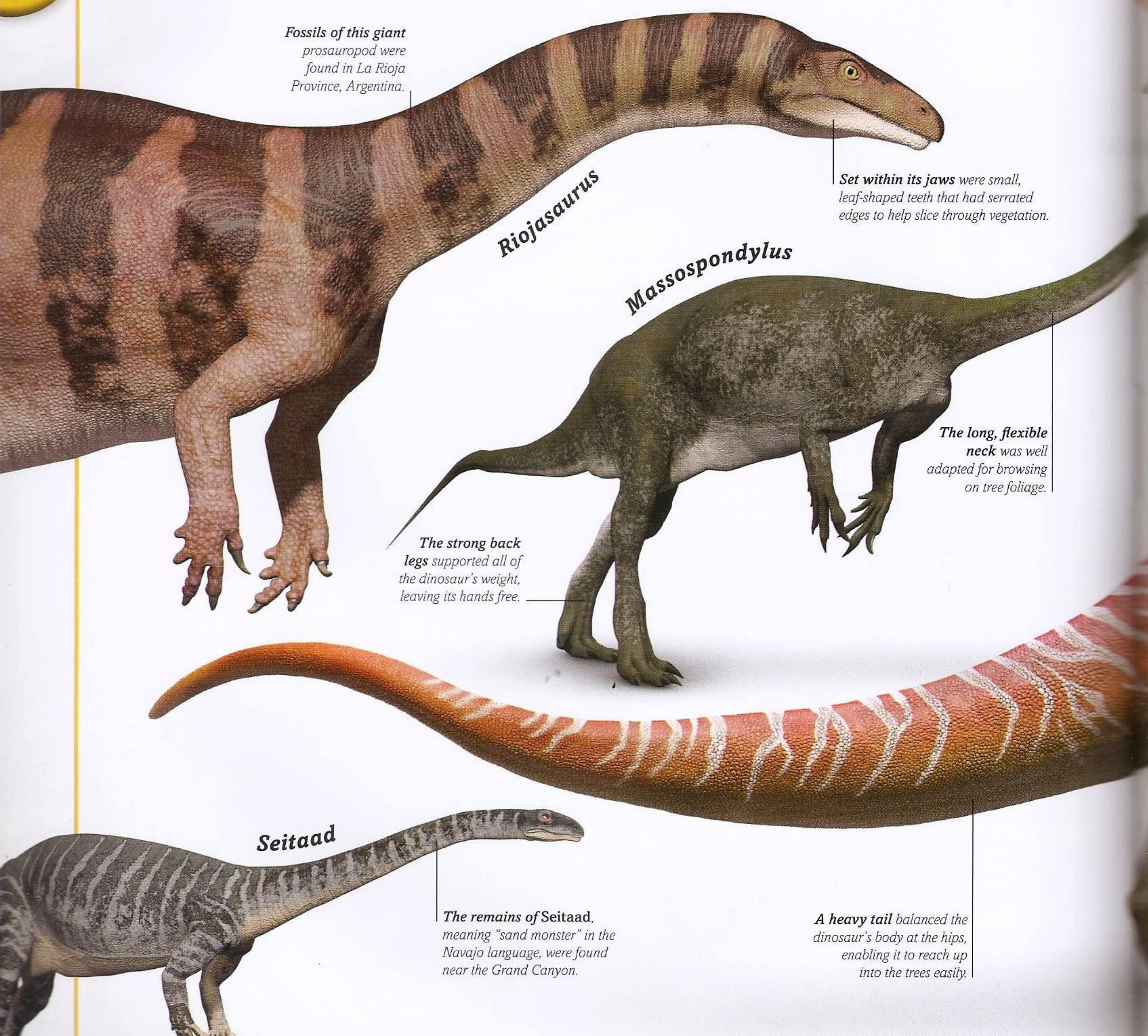
AGILE ARCHOSAURS

Early dinosaurs and their close relatives were all archosaurs, sharing features that make them hard to tell apart. They all had long legs held beneath the body, an agile build, and gaps in their skulls filled with air.



as well as small animals. These light, agile creatures were closely related to animals like ***Nyasasaurus***, which may have been one of the first true dinosaurs. The first definite dinosaurs—animals like ***Eoraptor***—lived about 230 million years ago and were probably omnivores that ate a variety of foods. They soon gave rise to specialized predators like ***Herrerasaurus***, as well as plant-eaters like ***Thecodontosaurus***. These animals were the ancestors of the giant dinosaurs that were to dominate life on land for the next 140 million years.

Prosauropods



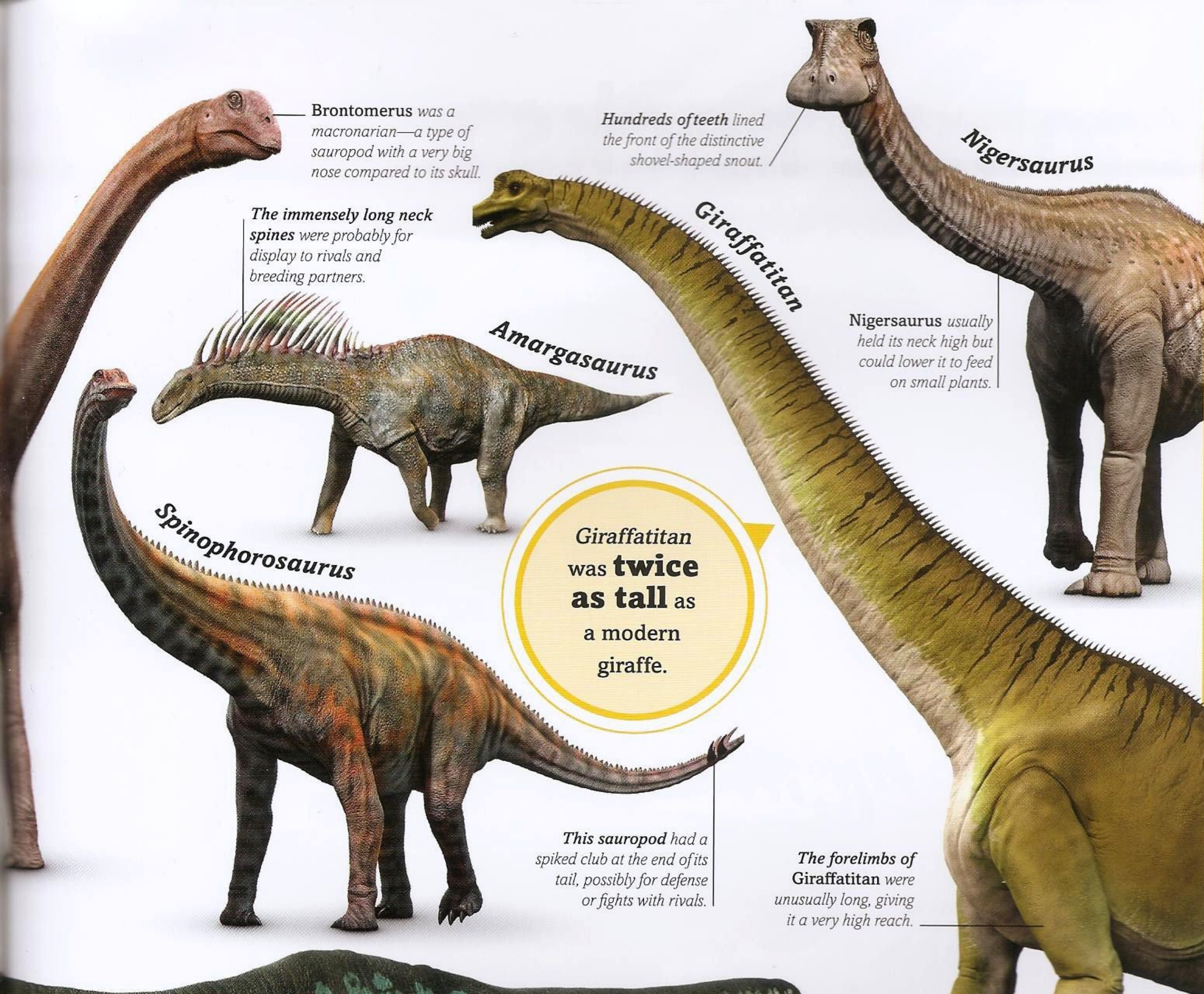
Soon after the evolution of the first dinosaurs in the middle Triassic (around 230–225 million years ago), dinosaurs began to diversify into species with different lifestyles. Some specialized in eating plants. They evolved long necks that helped them reach into trees, but their heads stayed relatively small. One of the earliest, ***Saturnalia***, was only about 6 ft (1.8 m) long, but its relatives were to get a lot bigger; by the late Triassic, ***Riojasaurus*** was about 33 ft (10 m) long and weighed as much as an elephant. These

Fossils of *Plateosaurus* have been found in more than **50 places** in Europe.

dinosaurs were the ancestors of the enormous sauropods, so they are known as prosauropods. They stood on two legs, balanced by their long tails, and used their shorter arms to gather food. ***Plateosaurus*** had grasping hands with four fingers and a powerful clawed thumb, which may also have been useful for defense. When it closed its jaws, its upper teeth overlapped the lower ones like scissor blades to slice through leaves. The tough, fibrous plant material was processed in a big digestive system to extract as much food value as possible.

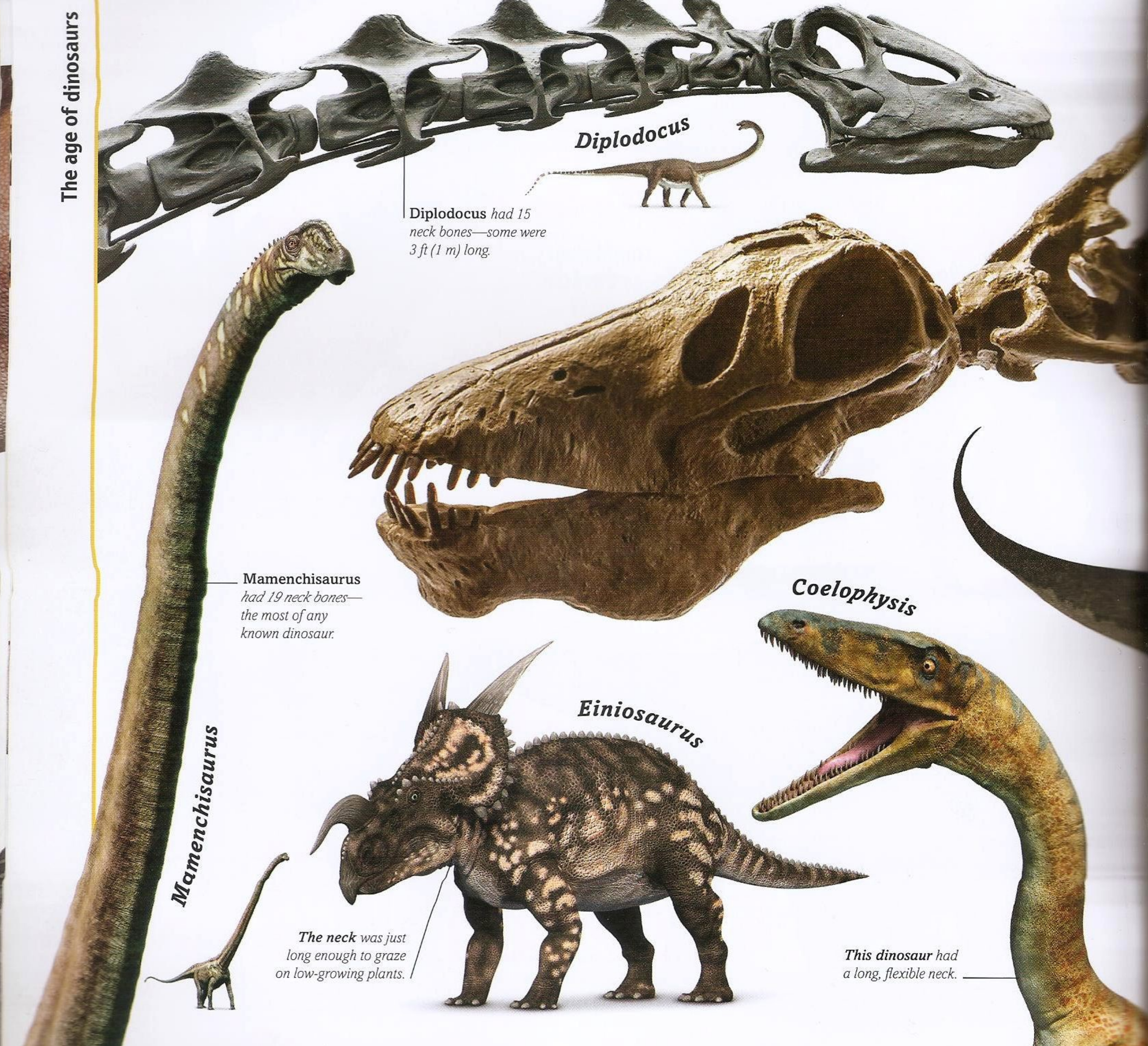
Sauropods

With their bus-sized bodies and elongated necks and tails, sauropods were the biggest dinosaurs ever to roam the Earth. These giants were plant-eaters; they would have browsed continually to fuel their enormous bodies. The earliest ones appeared about 200 million years ago and were similar to ***Barapasaurus***. Unlike their prosauropod ancestors, they used their arms to support their bodies, and their hands became weight-bearing feet. Despite this, many could probably rear up on their hind legs to feed in the treetops. Others,



like ***Sauroposeidon*** and ***Giraffatitan***, had long arms that helped raise their shoulders much higher than their hips, allowing them to reach the tallest trees without rearing up. The simple teeth of typical sauropods were adapted for biting or ripping leaves from trees, but not for chewing. They swallowed the leaves and relied on their huge digestive systems to process them. A few sauropods like ***Nigersaurus*** had more complex teeth at the front of their wide snouts. These teeth may have been specialized for eating plants growing at ground level.

Mobile necks



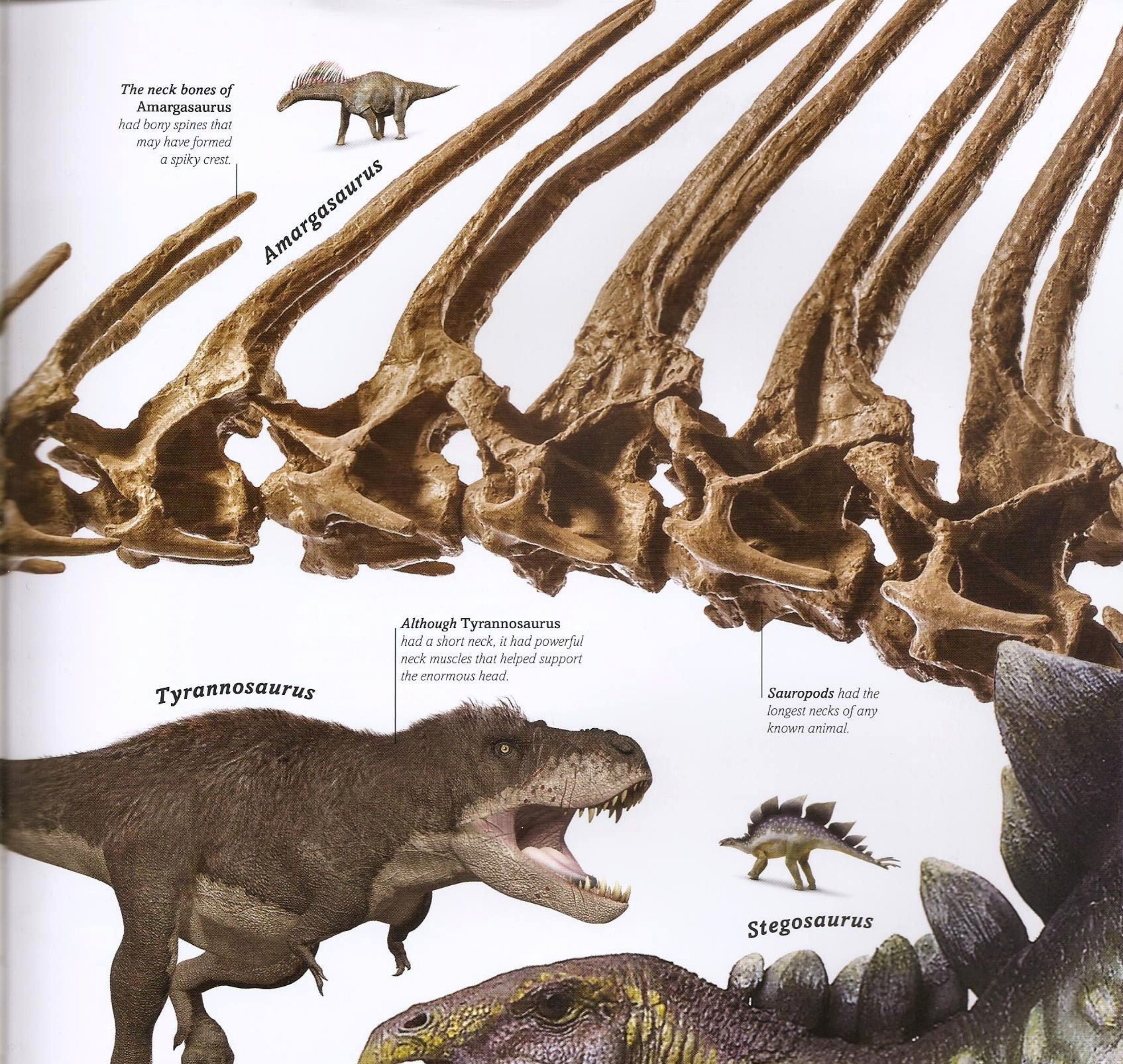
Diplodocus *had 15 neck bones—some were 3 ft (1 m) long.*

Mamenchisaurus *had 19 neck bones—the most of any known dinosaur.*

The neck *was just long enough to graze on low-growing plants.*

This dinosaur *had a long, flexible neck.*

Some dinosaurs—especially the plant-eating sauropods—had such astonishingly long necks that it is hard to imagine how they held their heads up. The neck of ***Mamenchisaurus*** could be up to 59 ft (18 m) long, which is eight times longer than the neck of a full-grown giraffe. Dinosaur neck bones, or vertebrae, were full of air cavities that made them light, enabling the animals to strip leaves from tall trees. Small, nimble



The neck bones of **Amargasaurus** *had bony spines that may have formed a spiky crest.*

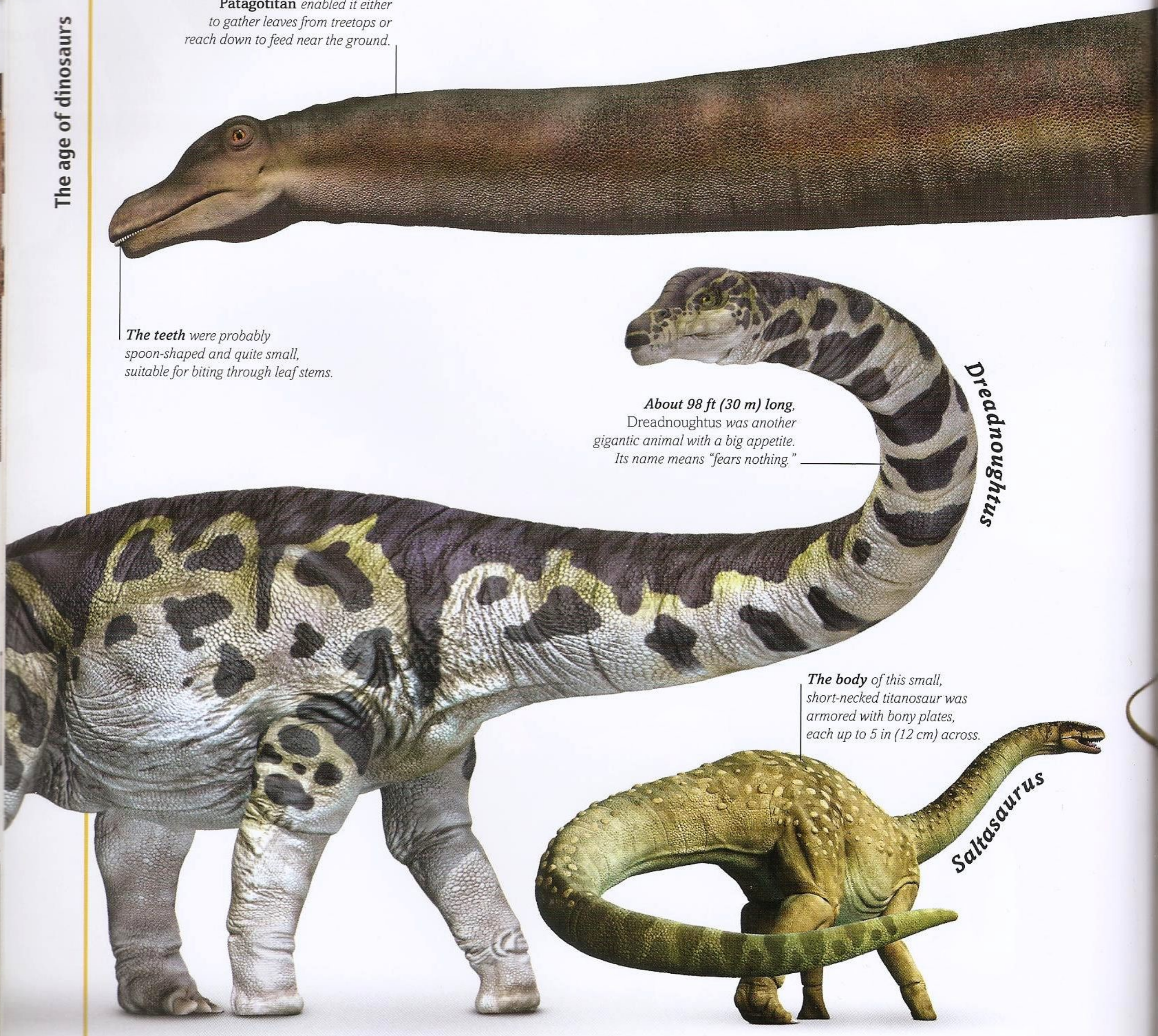
Although **Tyrannosaurus** *had a short neck, it had powerful neck muscles that helped support the enormous head.*

Sauropods *had the longest necks of any known animal.*

The underside of the neck *was protected by plates of bone hidden in the skin.*

predators such as ***Coelophysis*** had S-shaped necks that they could straighten in an instant to snap up small prey. Big hunters like ***Tyrannosaurus*** had stout, massively powerful necks to support their huge skulls and jaws and to give them the strength to tear prey apart. But most ornithischians, including ***Stegosaurus*** and ***Einiosaurus***, had relatively short necks suitable for feeding on low-growing plants.

Titanosaurs



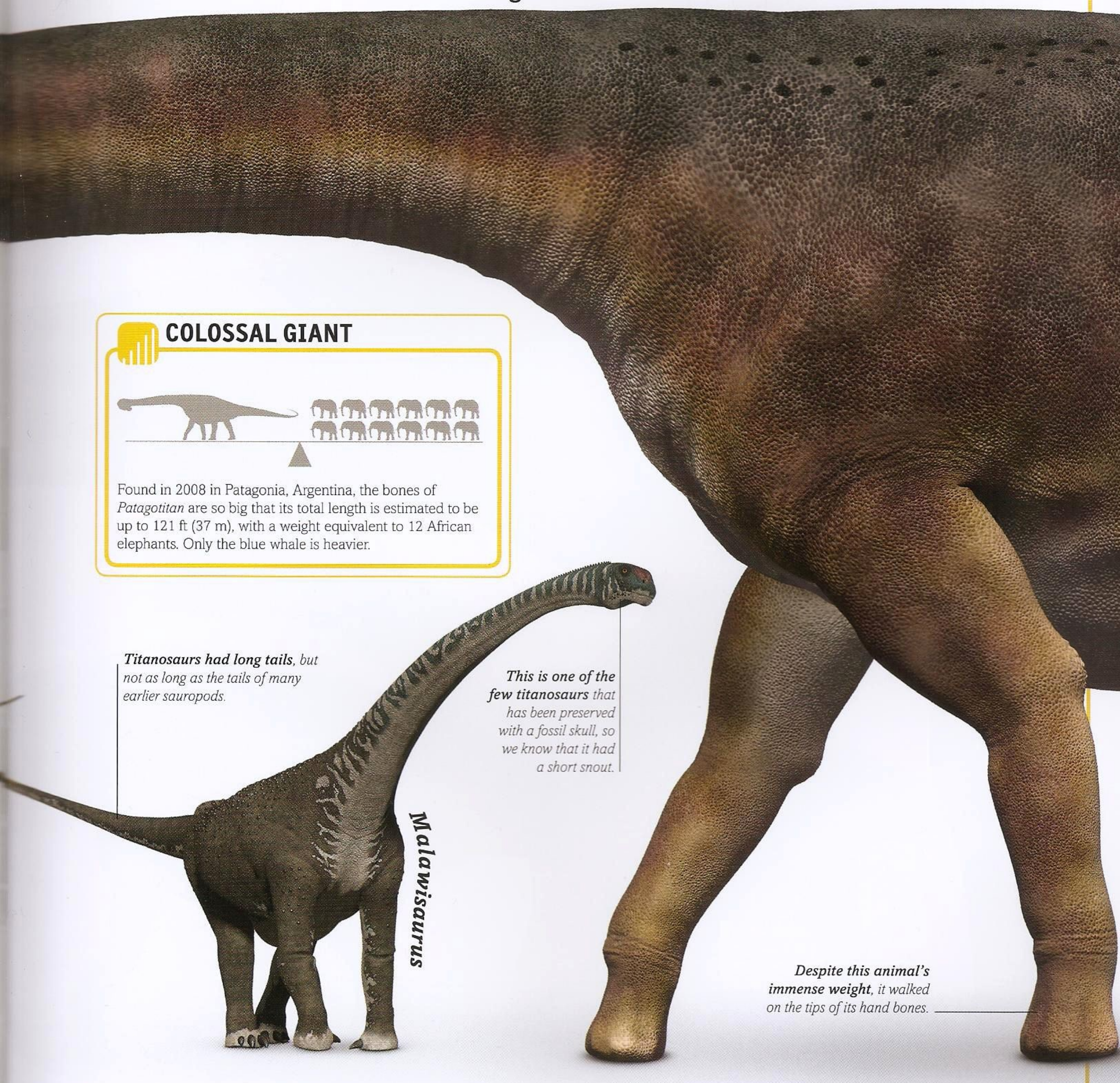
***The very long neck of* Patagotitan** *enabled it either to gather leaves from treetops or reach down to feed near the ground.*

***The teeth** were probably spoon-shaped and quite small, suitable for biting through leaf stems.*

About 98 ft (30 m) long, Dreadnoughtus *was another gigantic animal with a big appetite. Its name means "fears nothing."*

***The body** of this small, short-necked titanosaur was armored with bony plates, each up to 5 in (12 cm) across.*

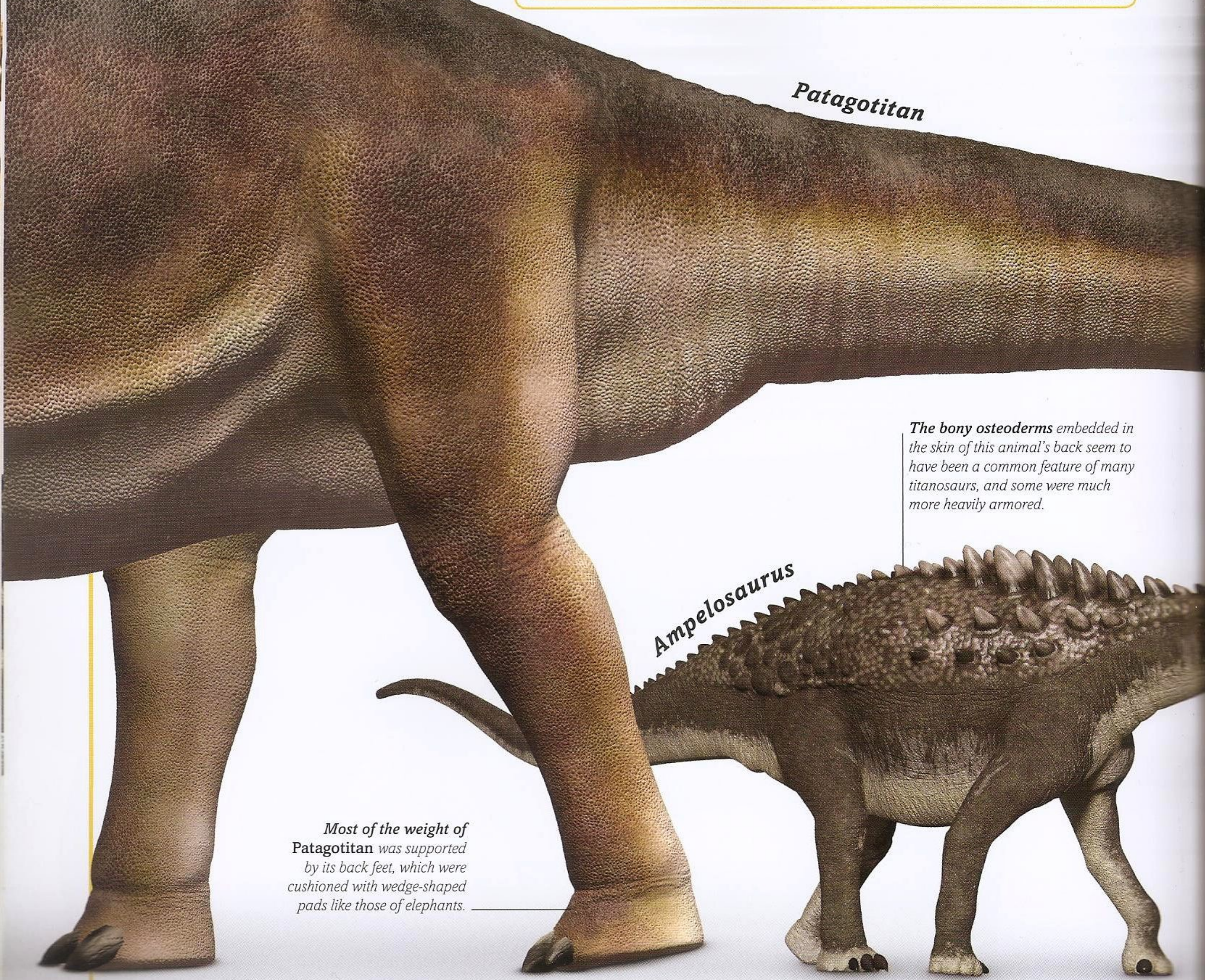
Until quite recently, scientists thought that the giant sauropods had mostly died out by the end of the Jurassic Period, 145 million years ago. But since the 1980s, many sauropod fossils have been discovered showing that they lived on and continued evolving until the very end of the age of dinosaurs. These late sauropods are known as titanosaurs. The name is misleading, because it suggests that they were all titanic giants. They were certainly big, and some of them were colossal—***Patagotitan***, for example, could turn



COLOSSAL GIANT

Found in 2008 in Patagonia, Argentina, the bones of *Patagotitan* are so big that its total length is estimated to be up to 121 ft (37 m), with a weight equivalent to 12 African elephants. Only the blue whale is heavier.

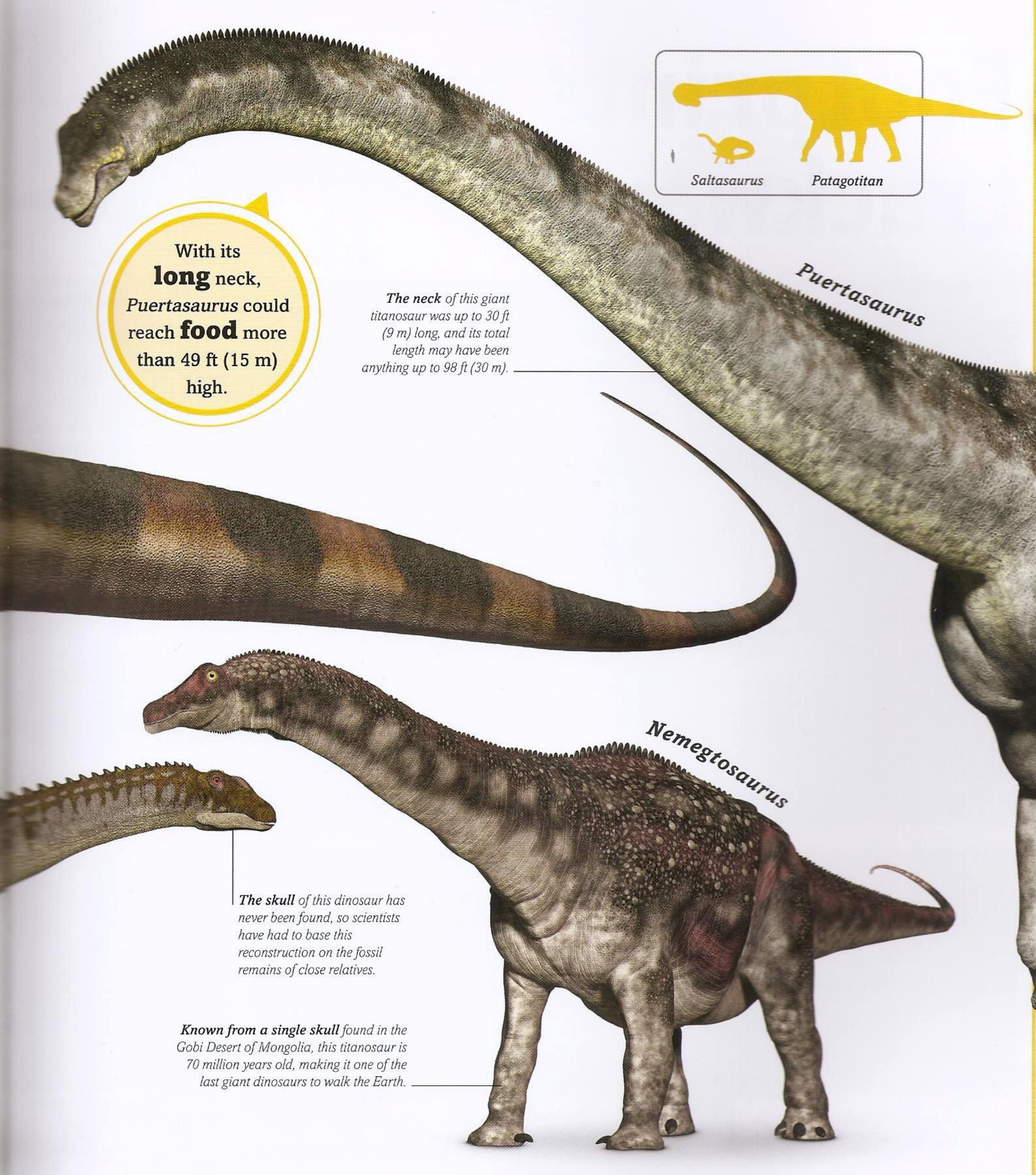
out to be the biggest land animal that ever lived. But other titanosaurs, including ***Saltasaurus*** and ***Malawisaurus***, were no bigger than elephants, which is small by sauropod standards. Over the 80 million years of their existence, the titanosaurs evolved many different head shapes and body forms, suited to a wide variety of feeding habits and lifestyles. Despite this, they were all herbivores, specialized for devouring vast quantities of leaves and other plant material. Fossil evidence also suggests that they probably lived in herds and nested together.



GLOBAL RANGE

Titanosaurs were first discovered in South America but have since been found in Europe, India, Mongolia, China, Africa, and even Antarctica—showing that they were a global success story.

In many ways, titanosaurs were typical sauropods, with long necks, long tails, and bulky bodies supported on all four limbs. In giants like ***Patagotitan*** and ***Puertasaurus***, their length, bulk, and especially weight were close to the maximum possible for a land animal. But they had other, more distinctive features. Their hands were better adapted for bearing weight than those of earlier sauropods, and later titanosaurs like *Saltasaurus* and ***Nemegtosaurus*** had no finger bones; they stood on pillarlike structures made up of the



With its **long** neck, *Puertasaurus* could reach **food** more than 49 ft (15 m) high.

The neck *of this giant titanosaur was up to 30 ft (9 m) long, and its total length may have been anything up to 98 ft (30 m).*

The skull *of this dinosaur has never been found, so scientists have had to base this reconstruction on the fossil remains of close relatives.*

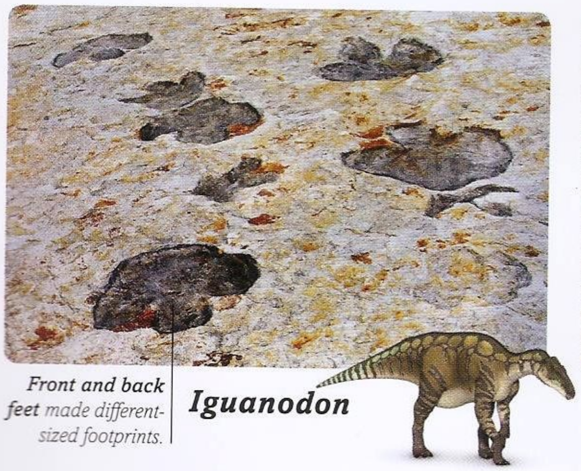
Known from a single skull *found in the Gobi Desert of Mongolia, this titanosaur is 70 million years old, making it one of the last giant dinosaurs to walk the Earth.*

same bones that form the palms of our hands. Titanosaurs had unusually broad chests, and this meant that their forelimbs were spaced wide apart; trackways of fossilized titanosaur footprints are easy to recognize because the marks left by their feet are so widely spaced.

Many titanosaurs also had a feature not seen in earlier sauropods—body armor. The skin of ***Ampelosaurus***, for example, was studded with tough, bony plates and spikes called osteoderms, which would have helped protect it from the teeth of big predators.

Footprints and trackways

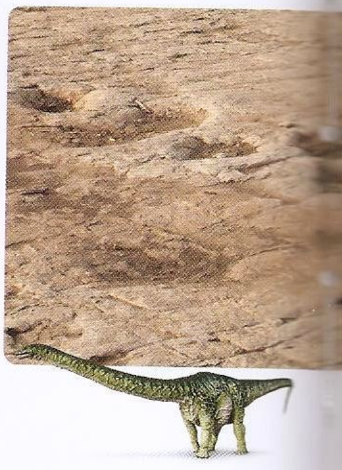
Found in Mongolia, **giant** footprints up to **6½ ft** (2 m) wide were made by titanosaurs.



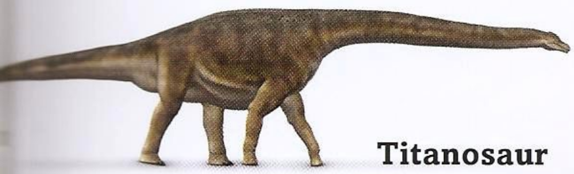
Front and back feet made different-sized footprints.

Iguanodon

Ankylosaurus



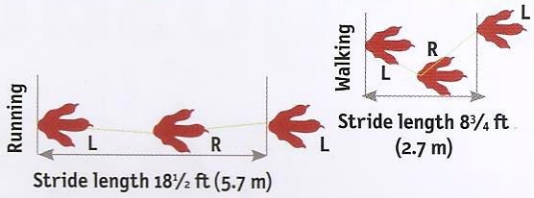
Fossilized bones can tell us a lot about how the dinosaurs were built, but less about how they lived. Fossilized footprints, however, can show how dinosaurs walked and ran and whether they lived alone or in a group. A single footprint does not tell us much more than what type of animal made it; the most interesting information comes from trackways—sets of footprints left by animals on the move. The angle and spacing of the prints show how they placed their feet. The spacing also reveals the stride length, and if this varies, it indicates

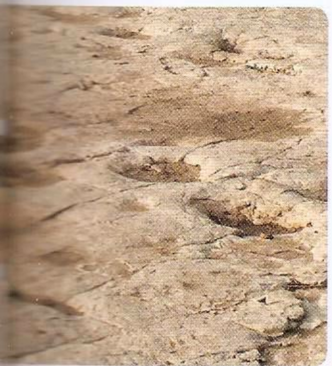


Titanosaur

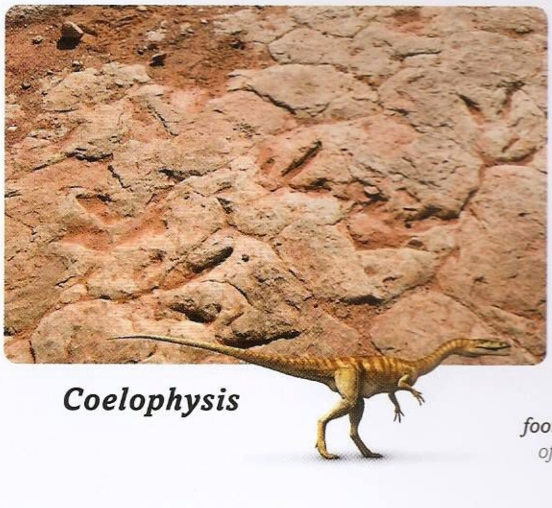
STRIDE LENGTH

If we know how long a dinosaur's legs were, the length of its stride indicated by a line of footprints can show how fast it was moving. It may also show it speeding up or slowing down.

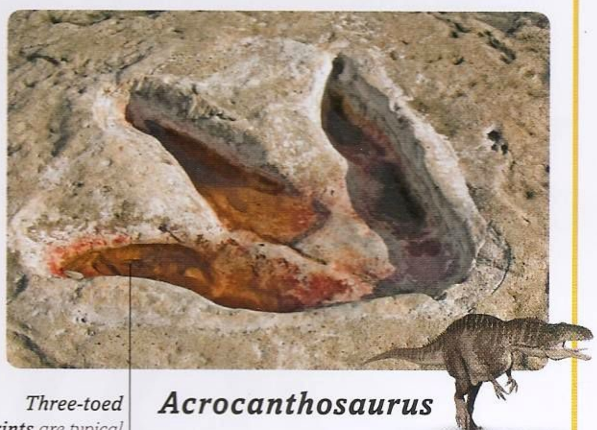




Apatosaurus



Coelophysis

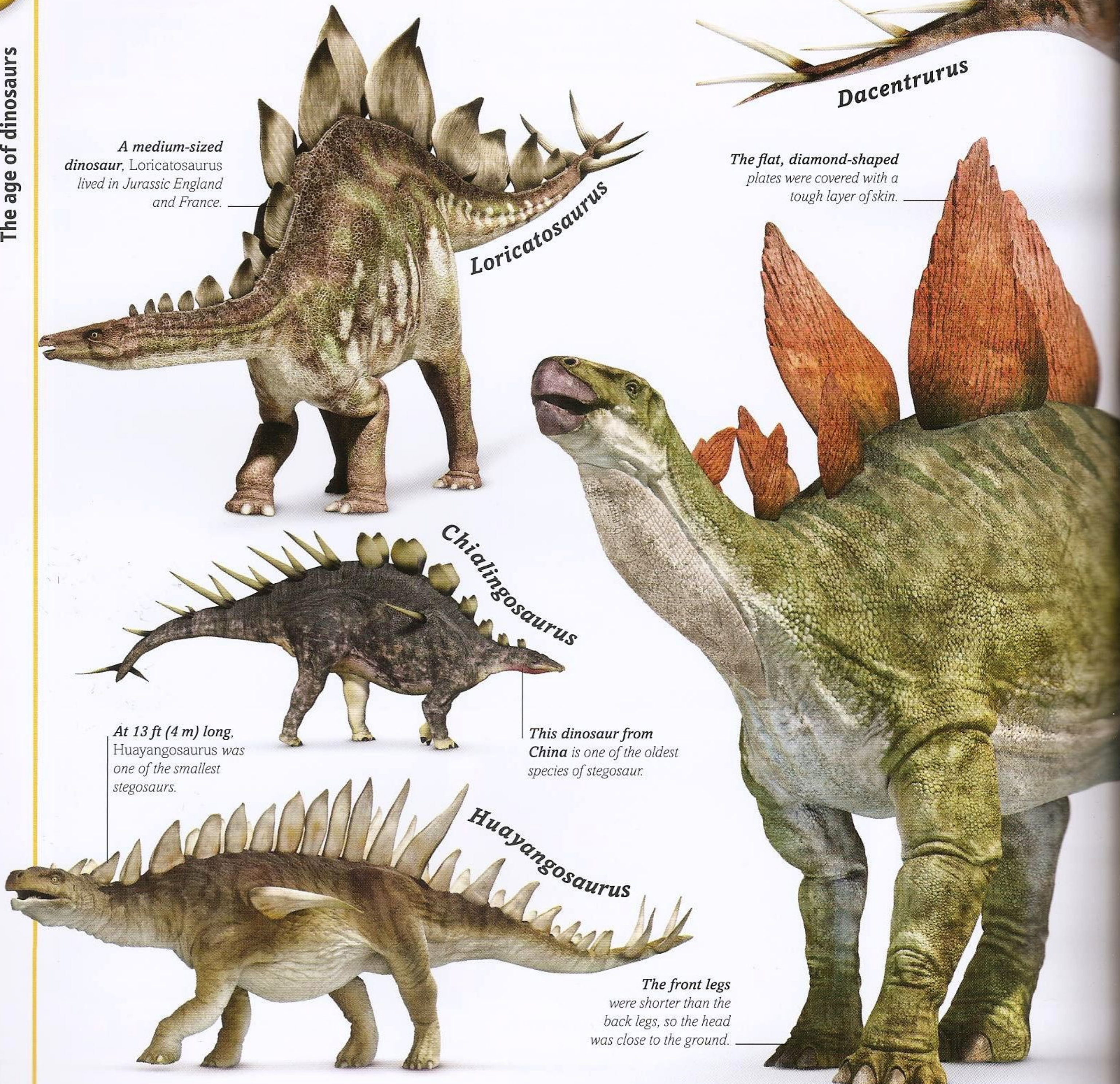


Three-toed footprints are typical of theropod hunters.

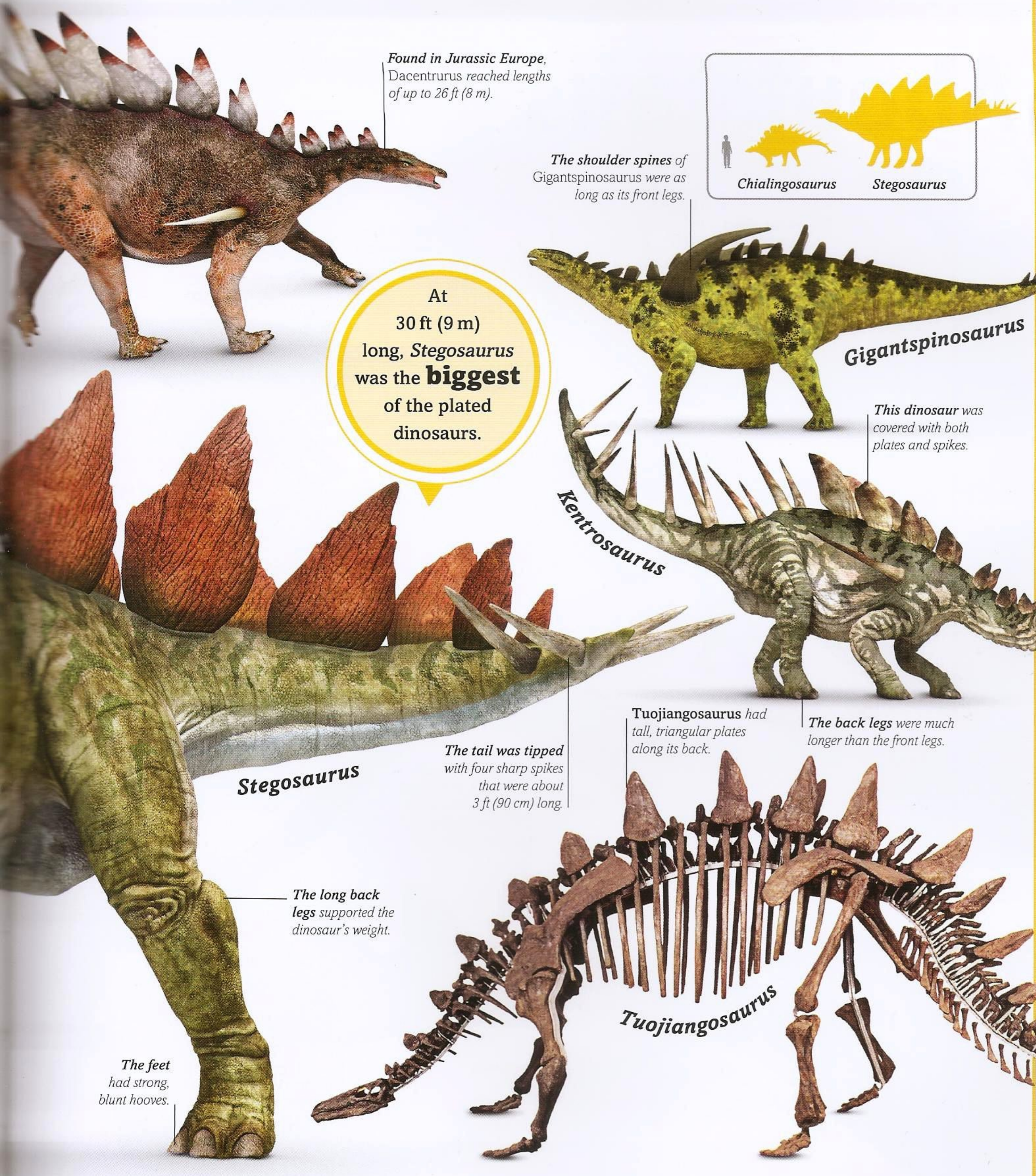
Acrocanthosaurus

a change of speed. Small and large footprints found together might have been left by a family, while a complex pattern of overlapping footprints could be evidence of a whole herd on the move. One 113-million-year-old trackway in Texas can even be read like a story, since it seems to show a big sauropod being stalked by a hunter—possibly the powerful theropod ***Acrocanthosaurus***. At one point, the footprints converge, perhaps revealing the exact spot where the predator made its attack.

Stegosaurs

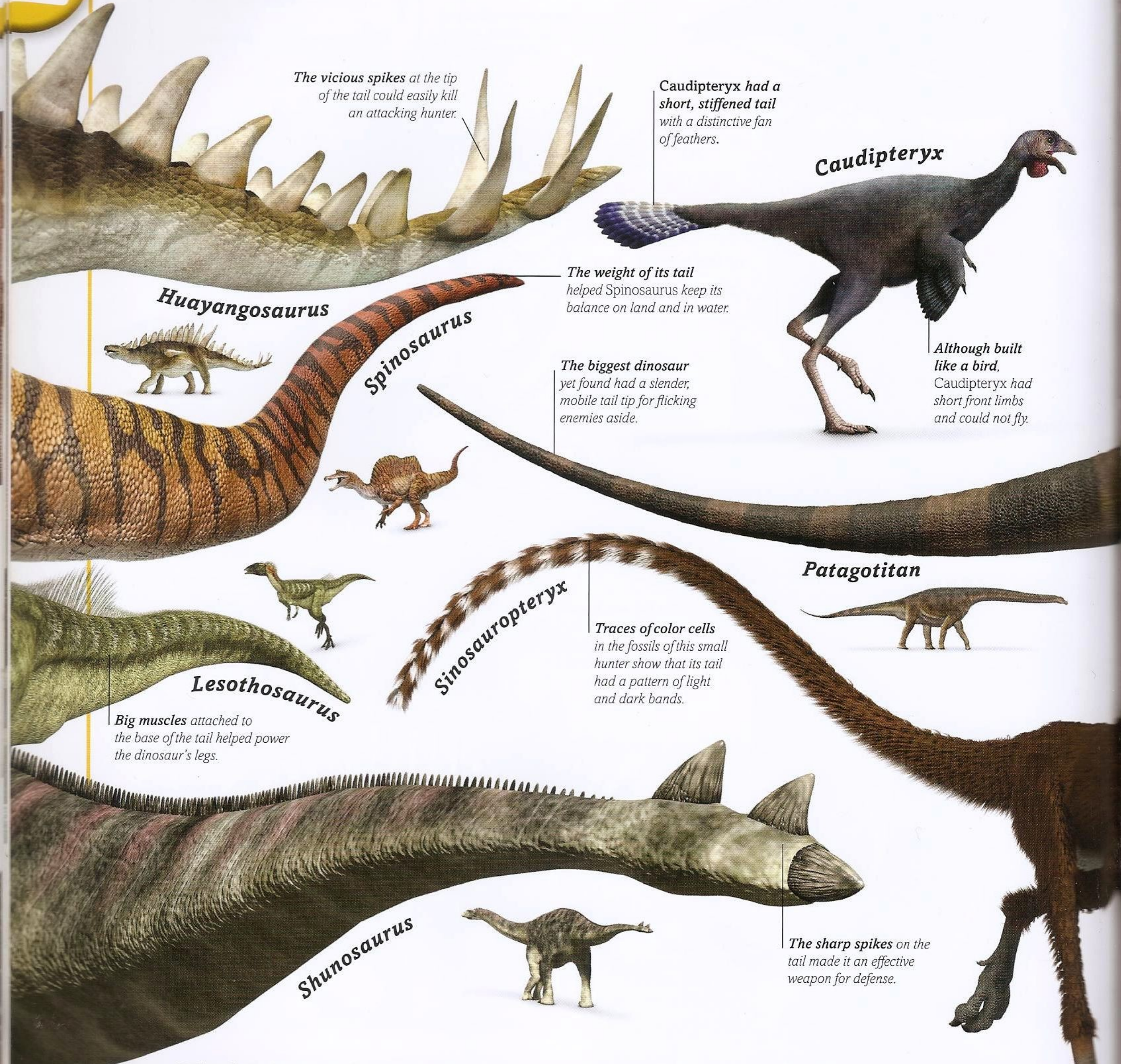


With a double row of tall, pointed, bony plates running down its back and tail, *Stegosaurus* is one of the most instantly recognizable dinosaurs. But it was just one of many similar stegosaurs that lived during the Jurassic and early Cretaceous Periods in various parts of the world—the US, Europe, India, China, and southern Africa. All stegosaurs were covered with plates and spikes along their backs, and many, such as the extra-spiky ***Dacentrurus*** and ***Kentrosaurus***, also had spikes sprouting from their shoulders. These may have been used



for defense, while the spikes on the end of a stegosaur's tail would certainly have been used to lash out at a predator. But the spectacular plates may have been brightly colored to attract a mate. All stegosaurs were plant-eaters, with narrow, beaked mouths that were ideal for gathering the most nourishing parts of low-growing shrubs and other plants. In relation to their size, they also had the smallest brain of any dinosaur—the elephant-sized *Stegosaurus* had a brain that was no bigger than a dog's.

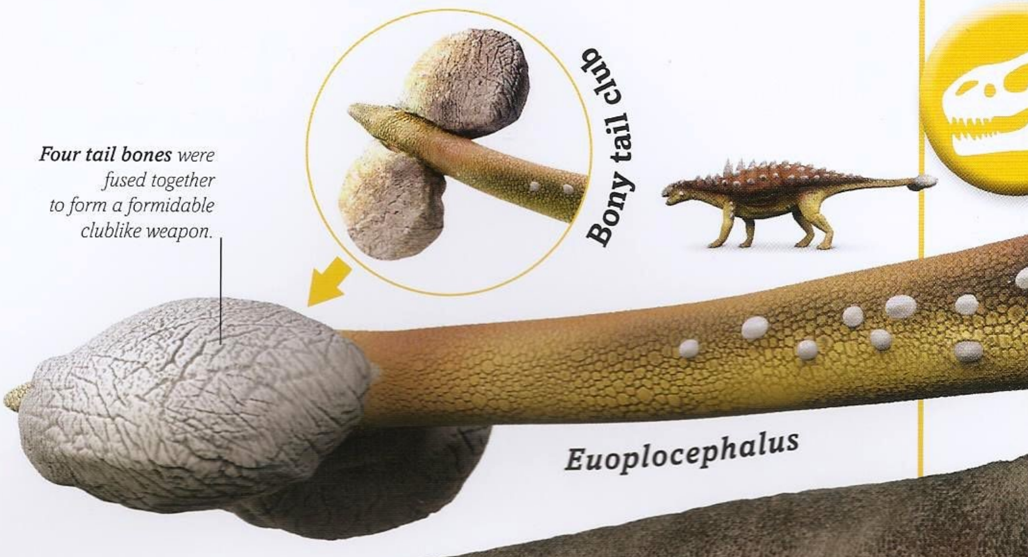
About tails



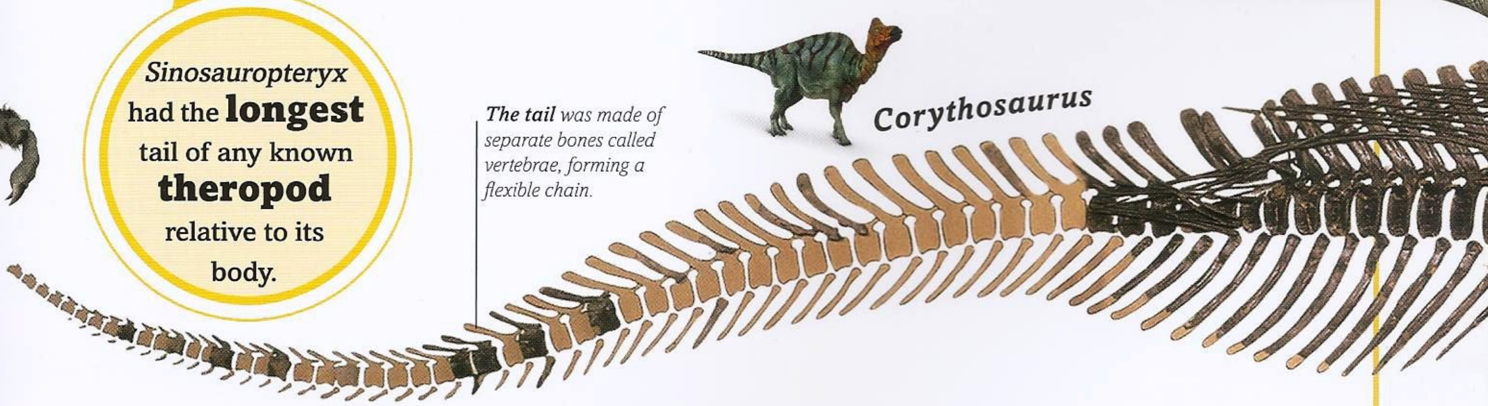
Whether long, spiked, clubbed, or feathered, dinosaur tails had different uses. Most of the big dinosaurs had long, bony tails equipped with powerful muscles. These heavy tails helped to balance the weight of the dinosaur's head and upper body. This was especially important for dinosaurs like ***Xiongguanlong*** that walked on their hind legs. The giant sauropod ***Patagotitan***, however, could sweep its long tail sideways like a whip with enough speed and force to knock a predator off its

FEATHERED EVIDENCE

Most of our knowledge of dinosaurs comes from their bones. But this lump of ancient amber (hardened tree resin) contains the entire tail of a small theropod dinosaur, complete with muscles and brown feathers.



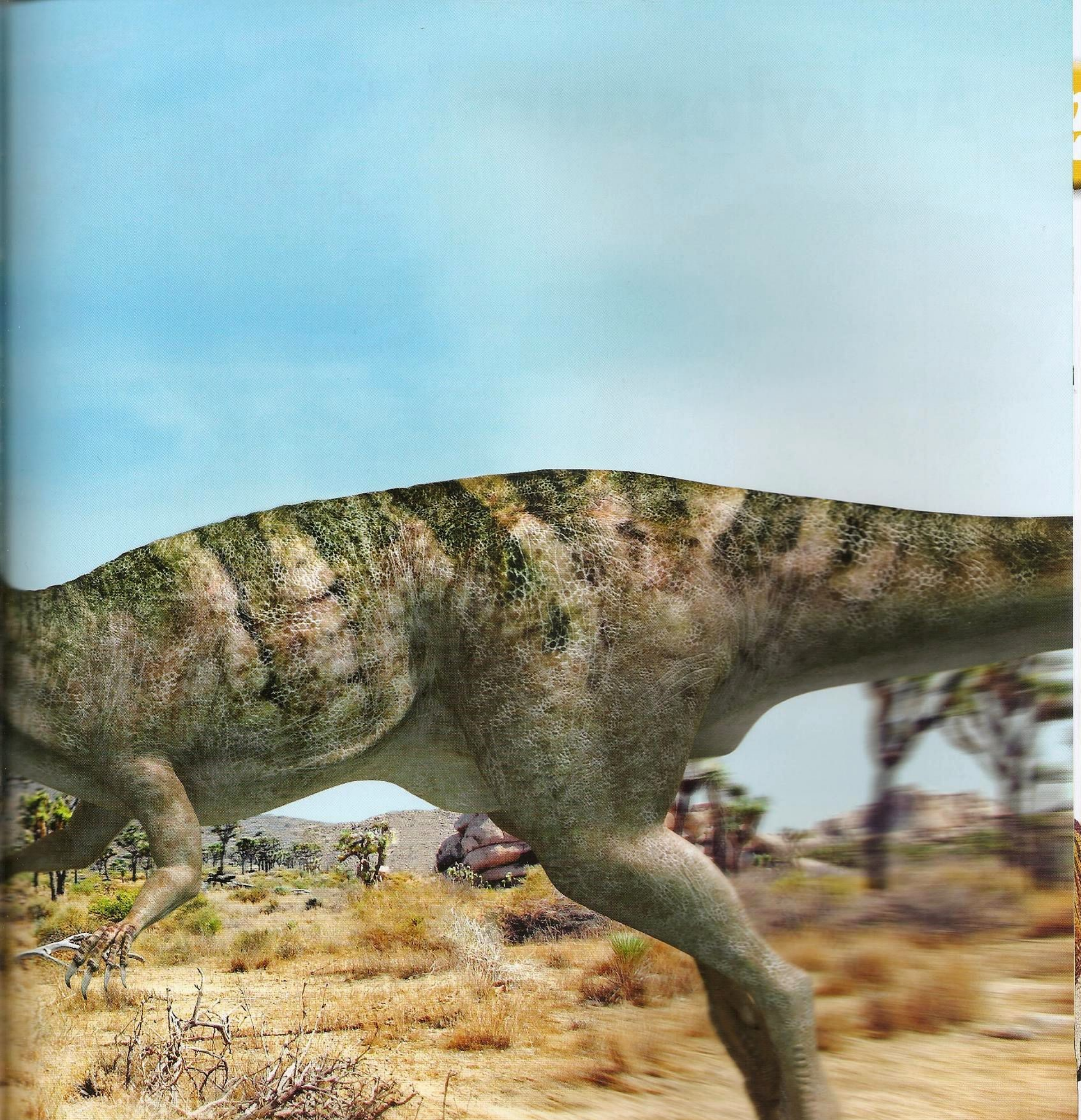
Sinosauropteryx had the **longest** tail of any known **theropod** relative to its body.



feet. The tail of ***Huayangosaurus*** was armed with two pairs of sharp spikes at the tip that made it a formidable weapon; the midsized sauropod ***Shunosaurus*** had a similar adaptation. Some ankylosaurs like ***Euoplocephalus*** had a massive, bony tail club that could be slammed into an enemy like a sledgehammer, shattering its bones. Some small theropod dinosaurs like ***Caudipteryx*** had short, bony tails with long feathers, just like modern birds. They may have been used for balance or to attract a mate.

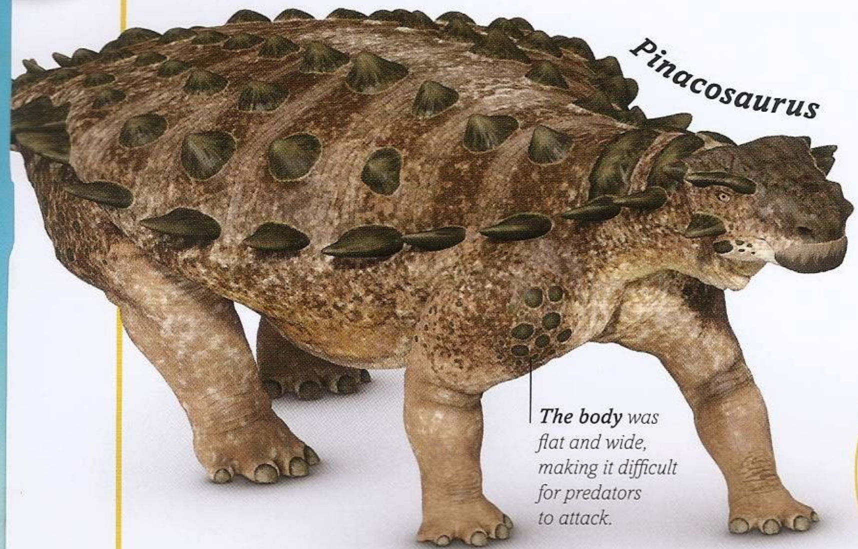
DEADLY SPIKES

For a hungry predator like *Ceratosaurus*, which lived in North America and Europe about 155 million years ago, a big, slow-moving stegosaur like *Dacentrurus* would have made a tempting target. The tall spikes on the stegosaur's back and tail certainly looked imposing, but could they cause any harm? Moving in to launch its attack, *Ceratosaurus* would soon find out—the hard way.

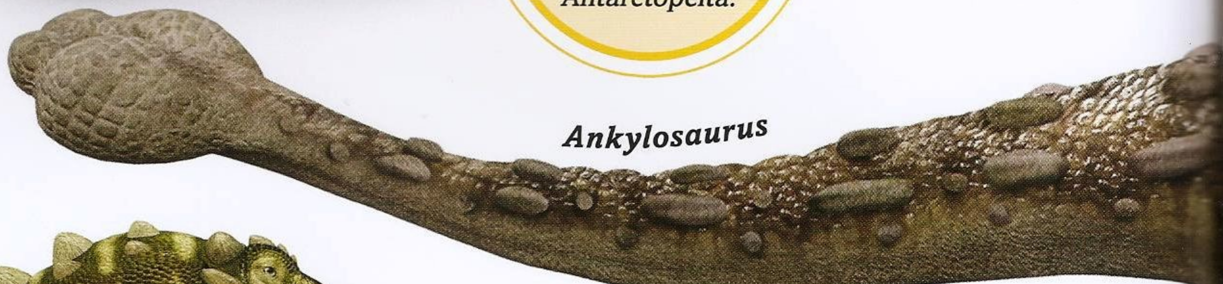


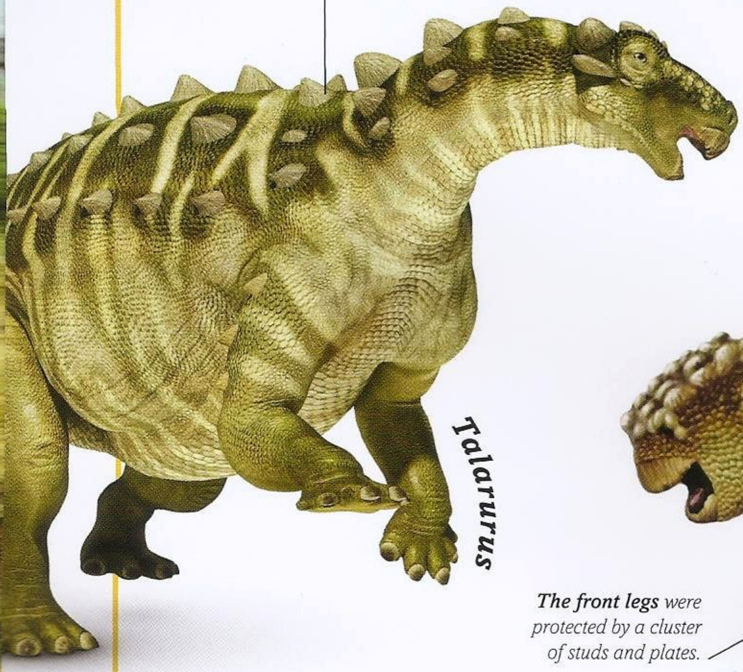
A hole in the tail bone belonging to another Jurassic predator, *Allosaurus,* was found to be a perfect match with a *Stegosaurus* tail spike. It is likely that the stegosaur was defending itself from an attack by swinging its tail like a spiked club. *Dacentrurus* was equipped in exactly the same way, with two pairs of stout, sharp-pointed spikes at the end of its tail. If an enemy like *Ceratosaurus* tried to creep up from behind—a common predatory tactic—it would be in for a nasty shock. With a flick of its spiked tail, the stegosaur could inflict terrible damage, blinding or even killing the hunter outright. It might have been a slow-moving plant-eater, but *Dacentrurus* could look after itself.

Ankylosaurs

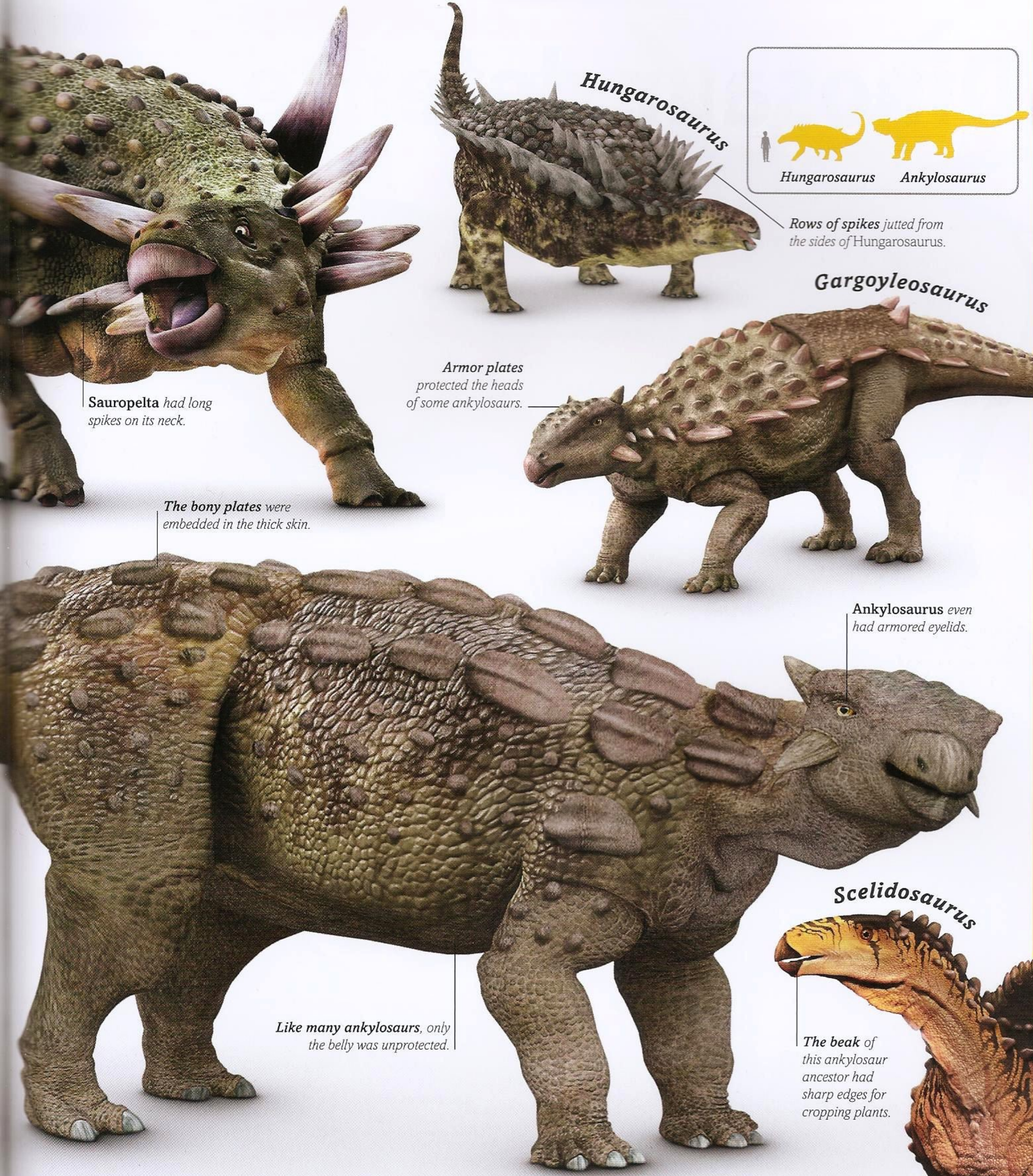


The **first dinosaur** found in **Antarctica** was the ankylosaur *Antarctopelta*.



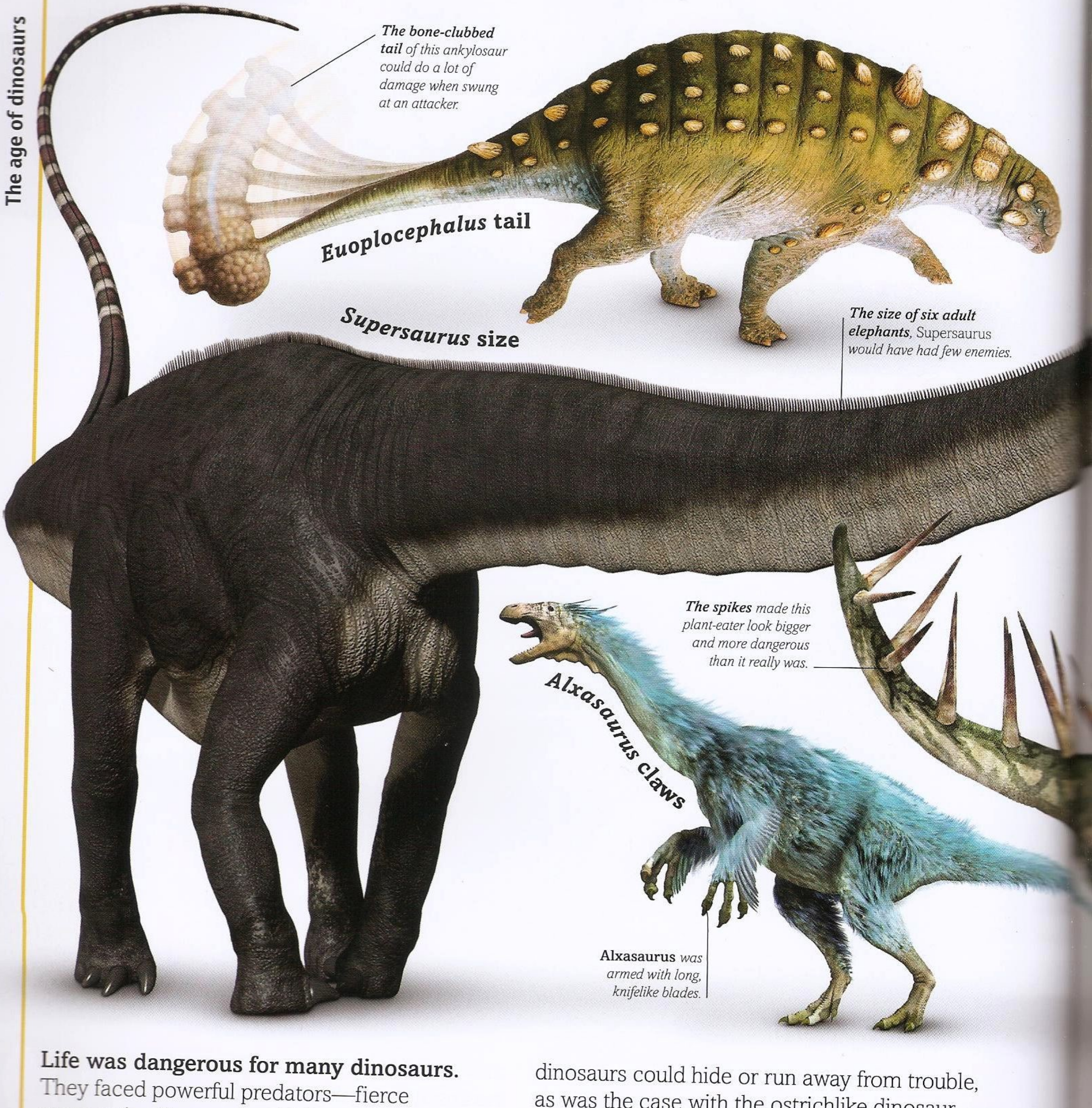


Protected from head to tail, the tanklike ankylosaurs first appeared about 175 million years ago. They were slow-moving plant-eaters, so without their body armor, they would have been easy targets for predators. Early ankylosaurs such as ***Scelidosaurus*** had bodies covered with bony plates and studs strong enough to break the teeth of any attacking dinosaur. But as predators got bigger and more powerful, ankylosaurs such as ***Saichania*** developed thick armor that may have discouraged even the massive-jawed



tyrannosaurs. Like several others, including ***Ankylosaurus***, *Saichania* also had a hefty tail club to swipe at predators, inflicting serious injury. Others, such as ***Sauropelta***, had long shoulder spikes that may have been as much for show as for defense. Many had broad mouths, ideal for gathering plant food in bulk, without being too selective, much like modern elephants. Their bulky bodies contained big digestive systems for processing their fibrous diet.

Dinosaur defense

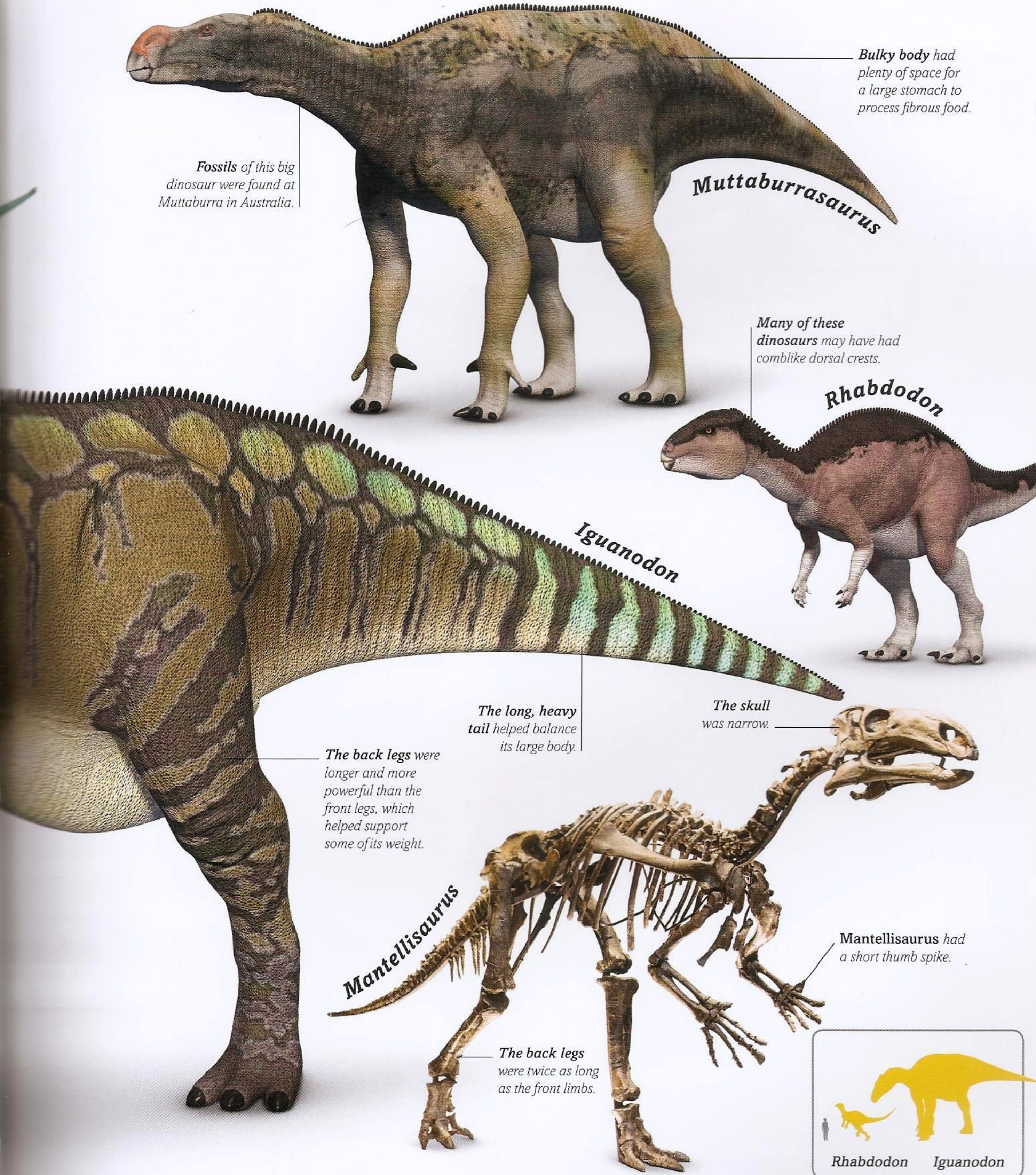


Life was dangerous for many dinosaurs. They faced powerful predators—fierce meat-eating theropods with huge jaws and big appetites. For a few giant dinosaurs like ***Supersaurus***, their sheer size was enough to make hunters choose easier targets. Small dinosaurs could hide or run away from trouble, as was the case with the ostrichlike dinosaur ***Struthiomimus***. The stiff bristles on the back of ***Heterodontosaurus*** may have deterred enemies like the quills of porcupines. The big plant-eater ***Kentrosaurus*** ("spiked lizard") was

heavily armored with plates and spikes. It could use its spiked tail as a defensive weapon, just like the club-tailed ***Euoplocephalus***, lashing out at an attacker. ***Styracosaurus*** had an impressive array of horns, which may have been useful in a tight corner. Others like ***Alxasaurus*** had long, curved claws on its hands that could inflict serious damage, and the bone-headed ***Pachycephalosaurus*** may have even charged its enemies head first. Sometimes attack was the best form of defense.

Iguanodontians

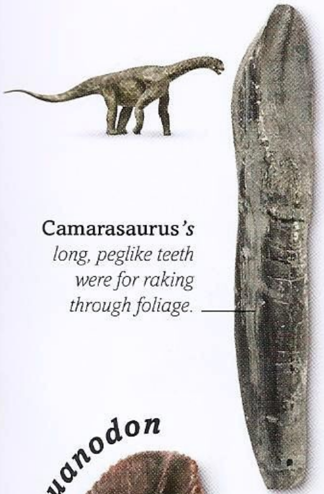
Among the very first dinosaur fossils to be discovered and scientifically identified was the tooth of an *Iguanodon*—one of the biggest plant-eating ornithopods. It was found in England in 1822, and given the name "iguana tooth" because of its similarity to the much smaller leaf-shaped teeth of present-day iguana lizards. Later, many entire skeletons of *Iguanodon* were found, with at least 38 discovered at one site in France, so it was probably a very common animal 135–125 million years ago. But *Iguanodon* was one of



many similar dinosaurs. They all had strong hind legs and shorter, weaker arms, and the smaller ones such as ***Dryosaurus*** may have walked on their hind legs. Many, including ***Tenontosaurus***, ***Muttaburrasaurus***, and the elephant-sized *Iguanodon* itself, were more heavily built and supported some of their weight with their forelimbs. Despite this, their hands were adapted for a variety of tasks, with hooflike middle fingers; a mobile grasping fifth finger; and a stout spike on the thumb that may have been used as a defensive weapon.

Plant-eaters

Plant-eating dinosaurs used their teeth in different ways. The long-necked sauropods and their relatives—animals like ***Diplodocus***—had specialized front teeth for gathering plants. Some used their teeth like combs to strip leaves from the twigs of trees and bushes. Many do not seem to have chewed their food, and just swallowed the leaves whole. Other plant-eaters like ***Edmontosaurus*** and ***Psittacosaurus*** had sharp beaks for gathering food, and specially adapted cheek teeth for chewing it. The teeth of some of these animals, such as ***Iguanodon***,



Camarasaurus

Camarasaurus*'s* *long, peglike teeth were for raking through foliage.*

Iguanodon

Iguanodon*'s* ***flattened teeth*** *had serrated edges.*

Rebbachisaurus

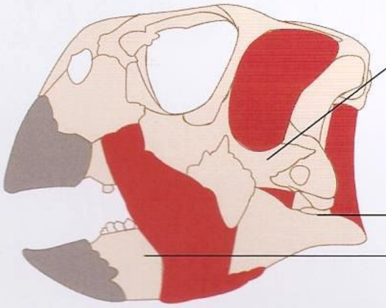
The leaf-shaped teeth *were ideal for snipping leaves from the twigs.*

The front teeth *were specialized for cropping low-growing plants.*

Hundreds of teeth *formed a complex grinding surface.*

JAW MOVEMENT

Most modern plant-eating animals chew their food. This involves grinding their teeth together using complex jaw movements—up and down, side to side, or forward and backward. The skulls and jaw bones of plant-eating dinosaurs show that some of these animals did the same. The jaws of *Psittacosaurus* and many hadrosaurs could slide forward and backward, and ankylosaurs could probably chew by moving their jaws from side to side, just like sheep.

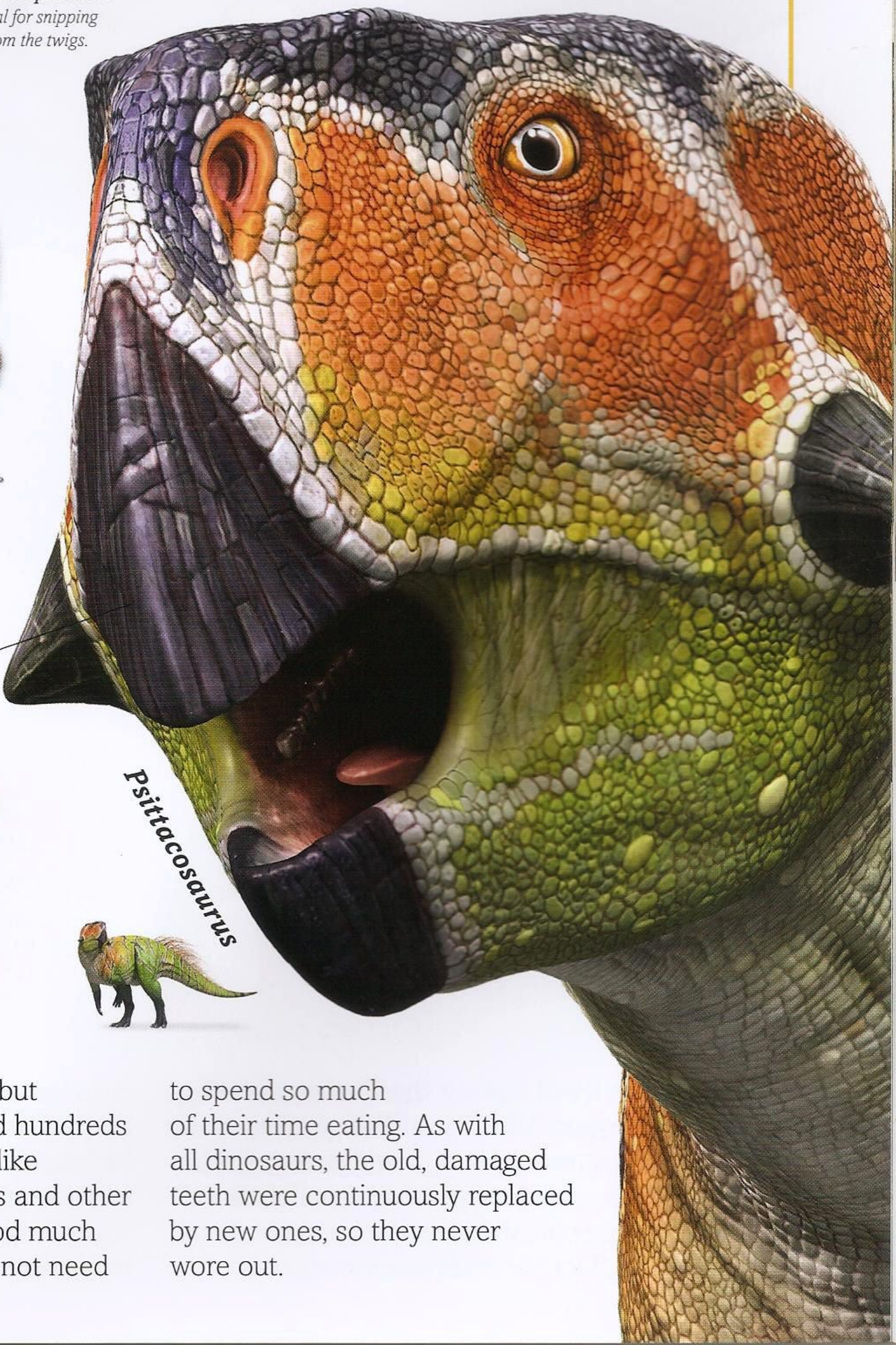


Jaw closing muscles were attached to rigid cheekbones.

Jaw joint

Jaws could slide forward and backward.

Psittacosaurus

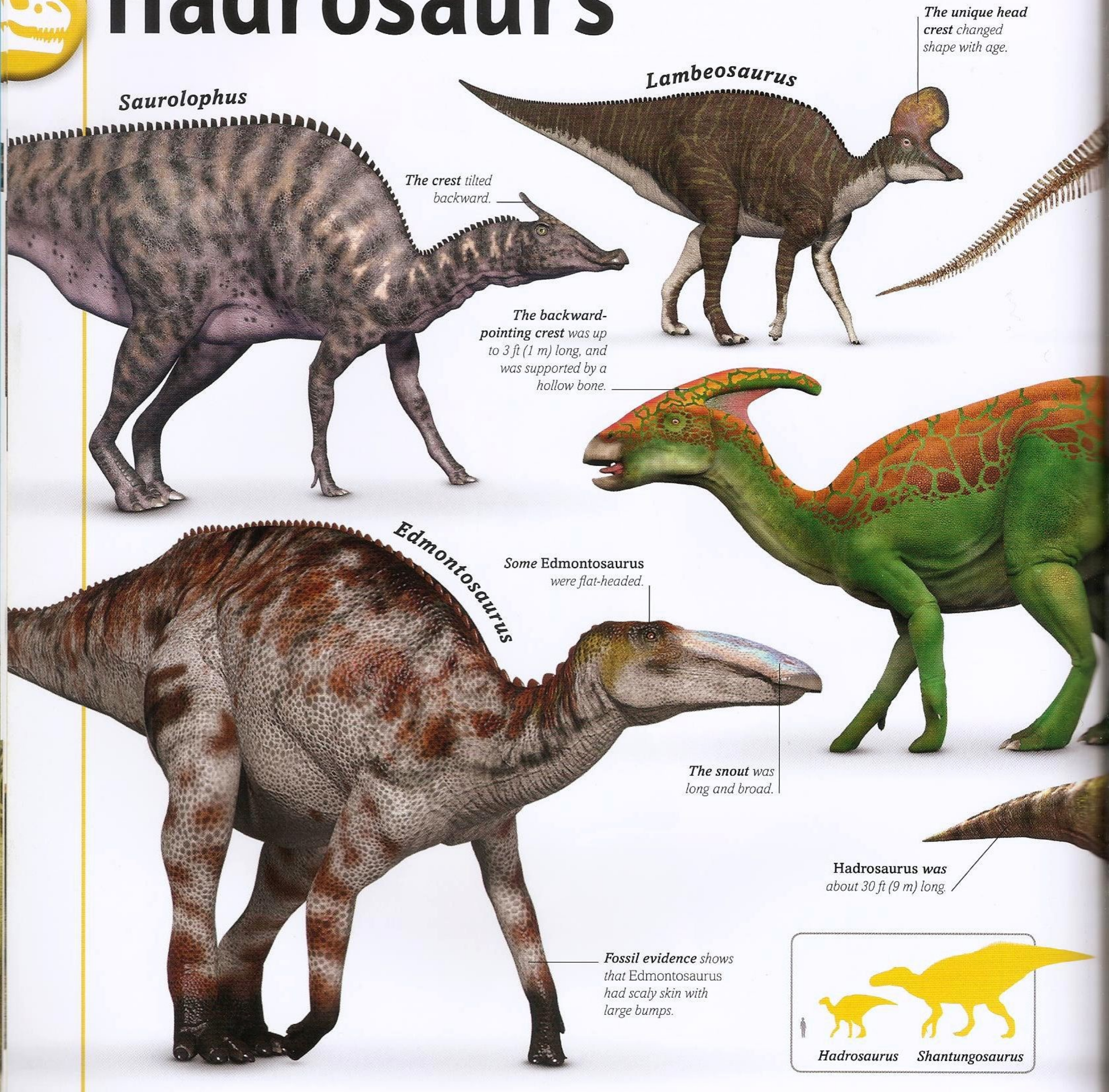


Psittacosaurus

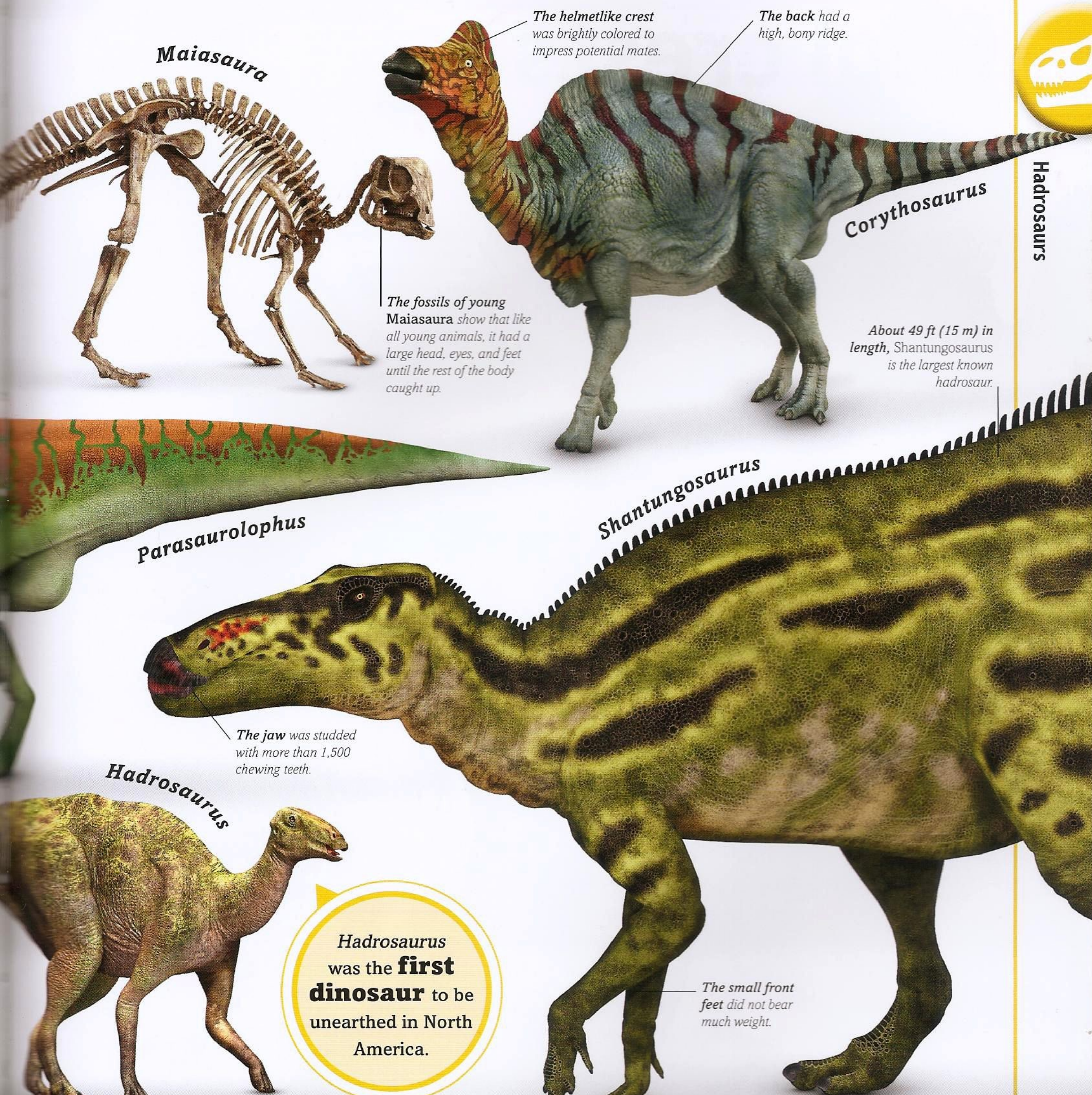
The parrotlike beak *was used to gather plant food and may even have been used to crack nuts.*

were saw-edged for cutting up leaves, but hadrosaurs such as *Edmontosaurus* had hundreds of teeth packed together to form a filelike surface, specialized for reducing leaves and other plant material to a pulp. This made food much easier to digest, so the hadrosaurs did not need to spend so much of their time eating. As with all dinosaurs, the old, damaged teeth were continuously replaced by new ones, so they never wore out.

Hadrosaurs

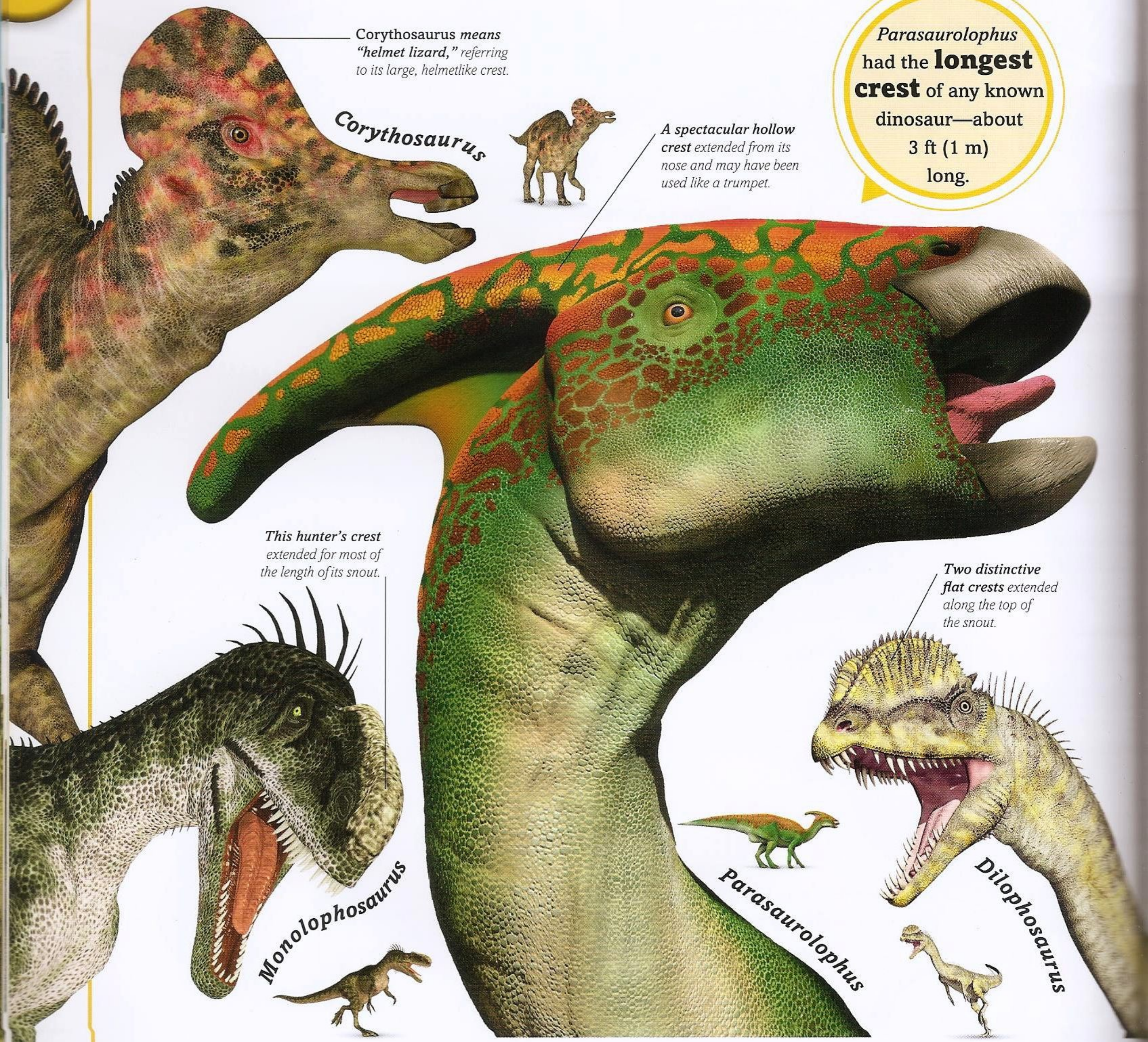


Hadrosaurs lived during the Cretaceous Period, between 100–66 million years ago. They roamed the forests and swamps of North and South America, Europe, and Asia. They were large plant-eaters, and many of them had a broad, ducklike beak that they used to crop leaves. Similar to earlier iguanodontians, but with more complex teeth and jaws, hadrosaurs had jaws lined with hundreds of teeth arranged like the teeth of a file. Grinding together, these teeth reduced tough plant food to a juicy, easily digested pulp, ensuring that a



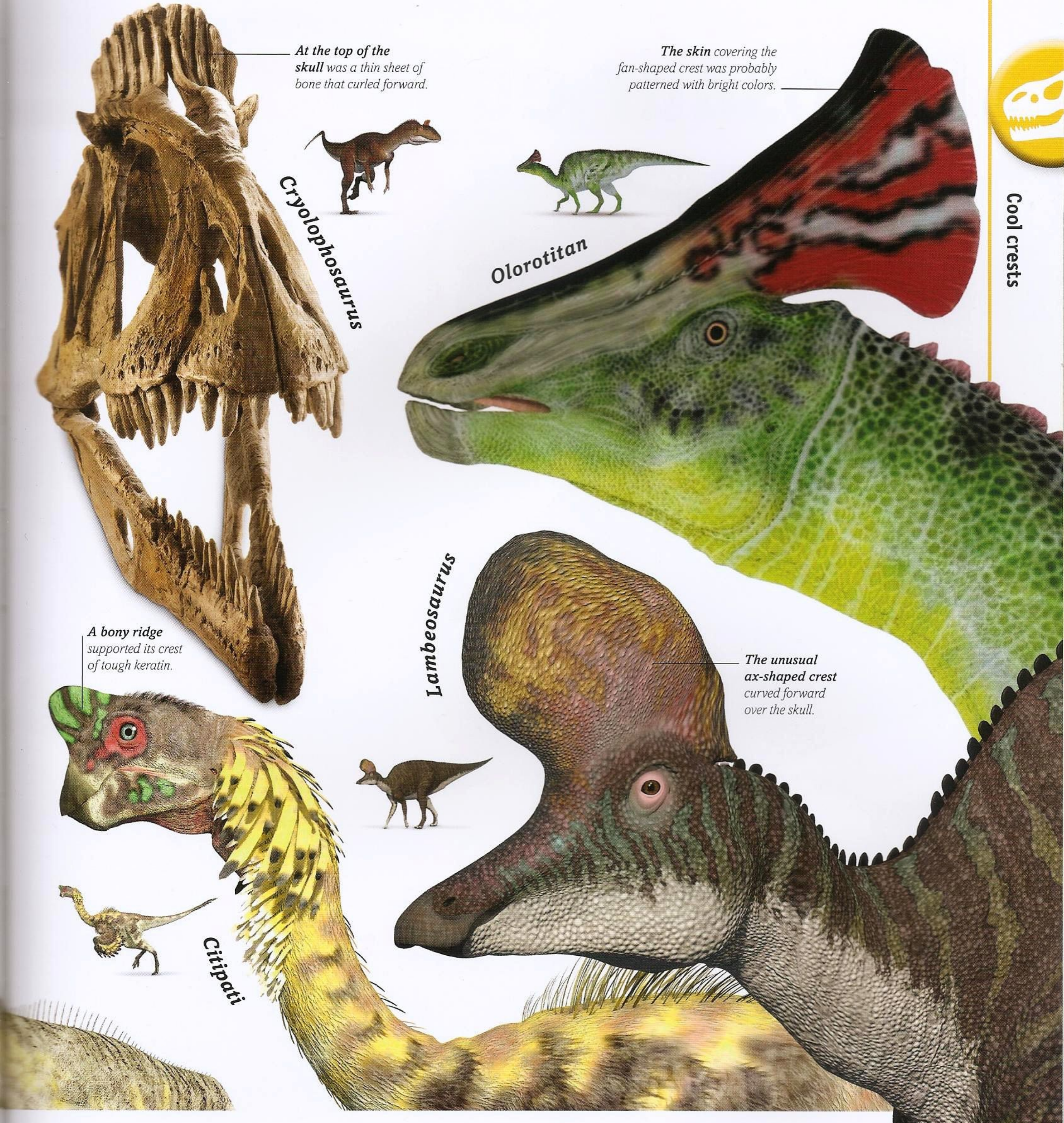
hadrosaur, such as ***Edmontosaurus***, got as much nutrition as possible from every mouthful. Many hadrosaurs, including ***Lambeosaurus***, also had impressive crests on their heads that could have been used to attract mates or for temperature control. The crests of some, such as ***Parasaurolophus***, formed bony tubes that may have helped to amplify their calls, making them sound like trumpeting elephants. They lived in herds, calling to each other to stay in contact as they roamed the forests of the Cretaceous world.

Cool crests



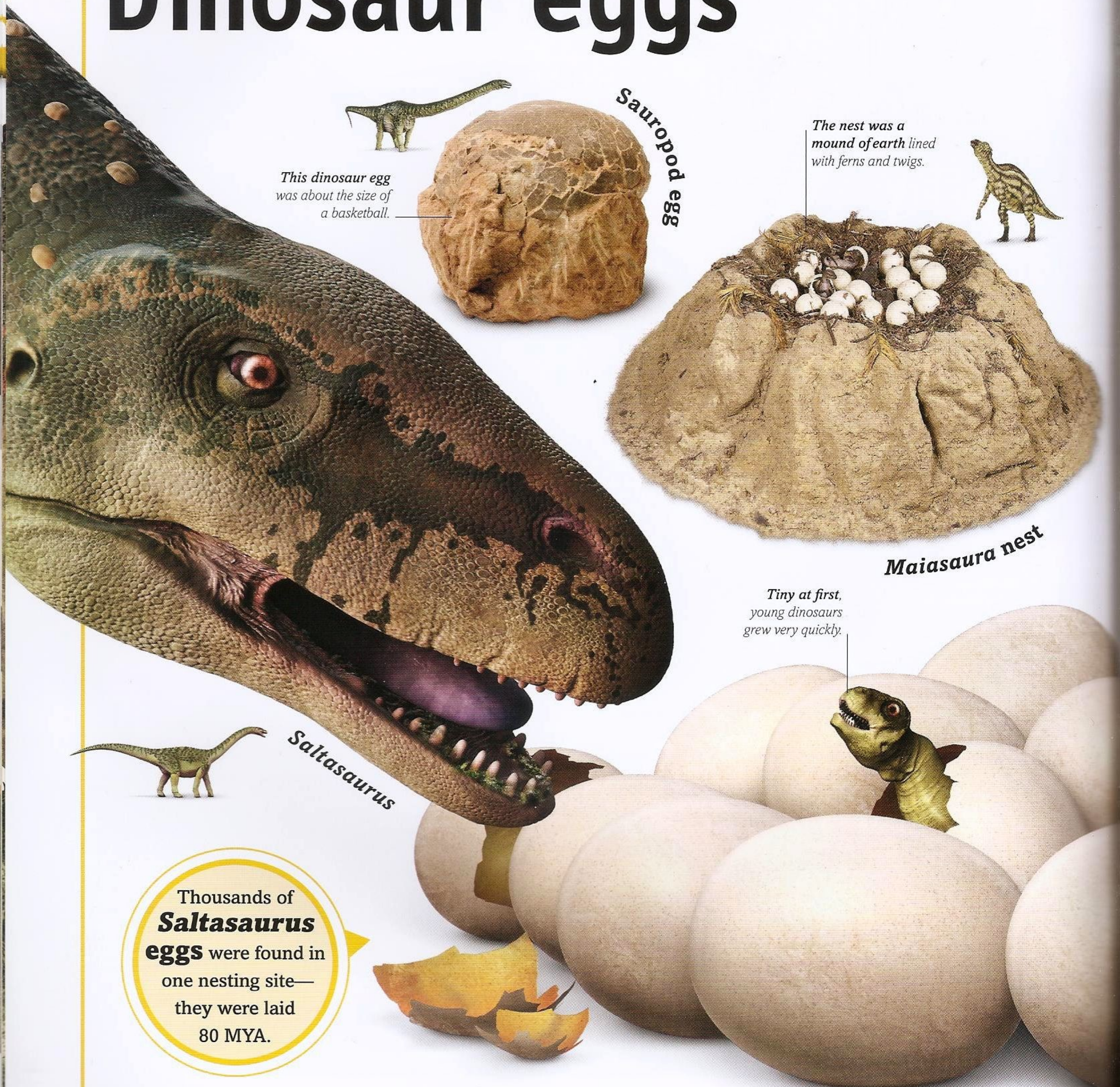
Parasaurolophus had the **longest crest** of any known dinosaur—about 3 ft (1 m) long.

The skulls of many dinosaurs were equipped with bony features that may have supported impressive crests. The bones were probably extended by extra structures made of tough keratin, like the horns of cattle or sheep, or covered by colorful skin. Some of the most spectacular crests belonged to hadrosaurs, such as ***Corythosaurus***, ***Olorotitan***, and especially ***Parasaurolophus***. The bones of these crests were hollow—possibly to make their calls louder, since the chambers in the crests of



many hadrosaurs were linked to their nostrils. But hadrosaurs were not the only crested dinosaurs. Several predatory theropods had crests, too, including the double-crested ***Dilophosaurus*** and a dinosaur found in Antarctica, ***Cryolophosaurus***. Crests were also a prominent feature of beaked, birdlike oviraptorids like ***Citipati***. All these bony extensions were for show, much like the colorful feathers of many modern-day birds.

Dinosaur eggs



Sauropod egg

This dinosaur egg *was about the size of a basketball.*

The nest was a mound of earth *lined with ferns and twigs.*

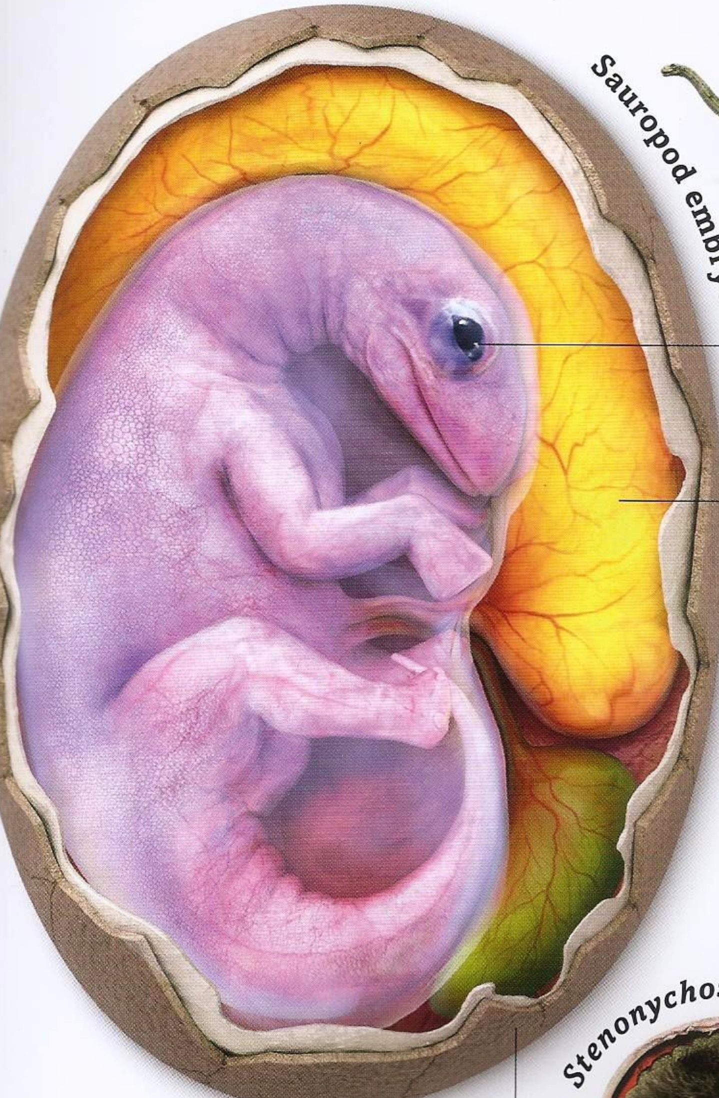
Maiasaura nest

Saltasaurus

Tiny at first, *young dinosaurs grew very quickly.*

Thousands of ***Saltasaurus* eggs** were found in one nesting site—they were laid 80 MYA.

Just like their closest living relatives, birds and crocodiles, all dinosaurs laid eggs. They had hard, chalky shells like birds' eggs, and at some fossil sites, the ground is covered in shell fragments. Where the eggs are intact, they have clearly been laid in nests on the ground. The biggest dinosaurs such as the **sauropods** seem to have buried their eggs in warm earth, or in piles of warm, decaying vegetation like modern crocodiles. The warmth was essential to make them hatch. Many smaller, lighter dinosaurs like



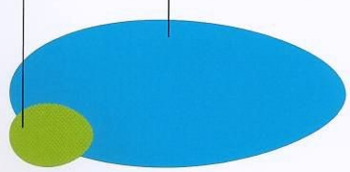
Sauropod embryo

The eyes only opened *when the dinosaur was ready to hatch.*

The yolk *contained all the food required for the unhatched dinosaur.*

The eggshell *was strong but thin enough to allow oxygen to get through to the embryo.*

COLOSSAL EGGS



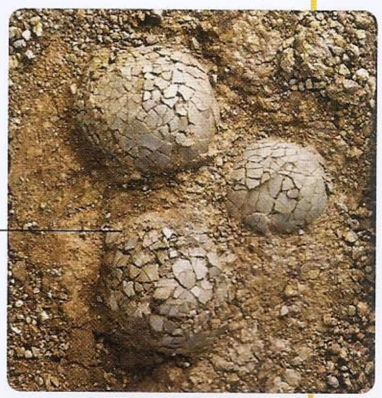
One of the largest-known dinosaur eggs belonged to a giant birdlike dinosaur called *Beibeilong sinensis*. The eggs were discovered in China in a nest that was 30 ft (9 m) wide.

Oviraptor nest

These fossilized eggs *were found in the Gobi Desert of Mongolia.*

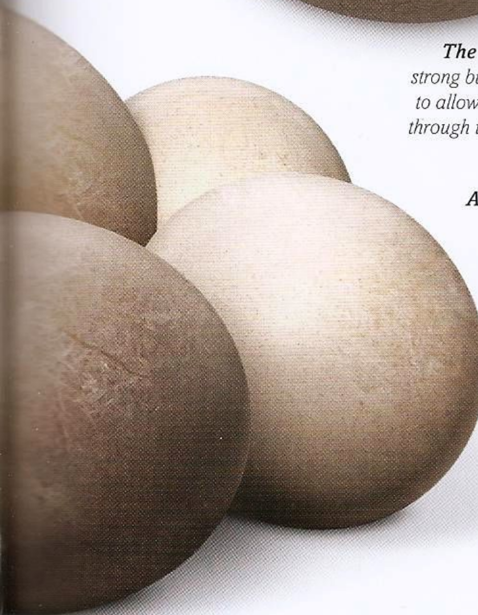
Stenonychosaurus embryo

A* Stenonychosaurus *baby *would have had its head tucked between its legs—* Stenonychosaurus *was a feathered theropod dinosaur.*



Found in clutches *of up to 40, these titanosaur eggs are almost spherical.*

Titanosaur eggs



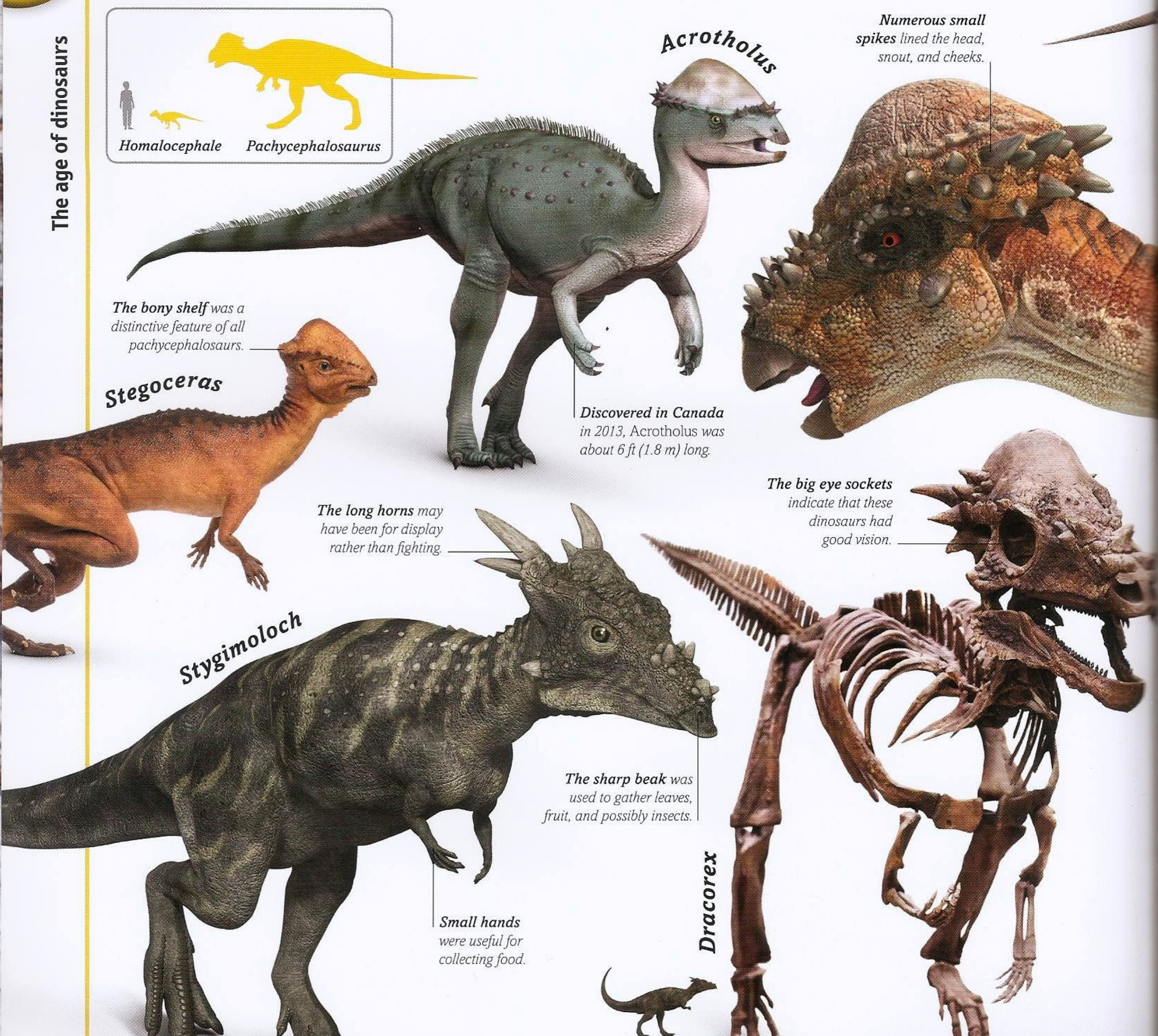
Oviraptor kept their eggs warm by sitting on them, just as most modern birds do. We know this because the fossilized remains of the adult dinosaurs have been found sitting on their eggs. The long-armed, feathered theropod dinosaurs known as maniraptorans may even have used their long "wing" feathers to brood and protect their eggs. The adults of some dinosaurs such as the hadrosaur ***Maiasaura*** ("good mother lizard") cared for their newly hatched young, bringing food for them and driving away predators.

DINOSAUR CRÈCHE

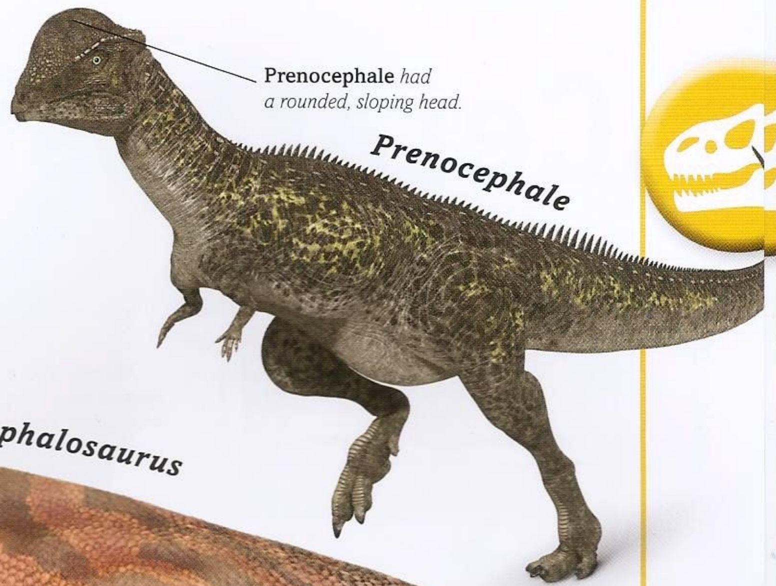
Around 125 million years ago, a catastrophic mudflow or fall of volcanic ash in what is now eastern China overwhelmed a nest of baby *Psittacosaurus*. They were buried along with a half-grown adult, just 6 years old. Found in 2004, their fossils seem to prove that the babies were being cared for after hatching and that their carer might not even be their parent.

Many modern animals, from songbirds to wolves, live in extended families where the half-grown young help their parents look after the babies. Some birds such as ostriches also lay their eggs in communal nests or guard their young in crèches. The *Psittacosaurus* nest contained a huge family of 34 young. It seems likely that they had more than one mother and that they were being looked after by a babysitter—probably the elder sister or brother of some of the babies. If so, such childcare may have been common among dinosaurs. *Psittacosaurus* was an early ceratopsian—an ancestor of animals like *Triceratops*. Maybe these horned giants looked after their young in the same way.

Pachycephalosaurs

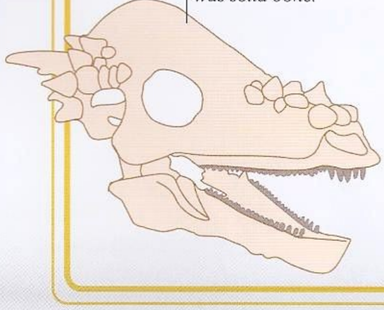


Also known as "boneheads," referring to their incredibly thick, strong skulls, pachycephalosaurs were unusual-looking dinosaurs. The largest of the boneheads was ***Pachycephalosaurus***. Its skull alone, the biggest so far, was up to 16 in (40 cm) thick and ringed with small, bony spikes. It is likely that the strong skull protected the animal's brain from regular impact inflicted during fights with rivals over status. But not all pachycephalosaurs had the same skull form. The smaller ***Homalocephale*** had a flat-topped head,



Only a **skull** of *Pachycephalosaurus* has been **discovered**.

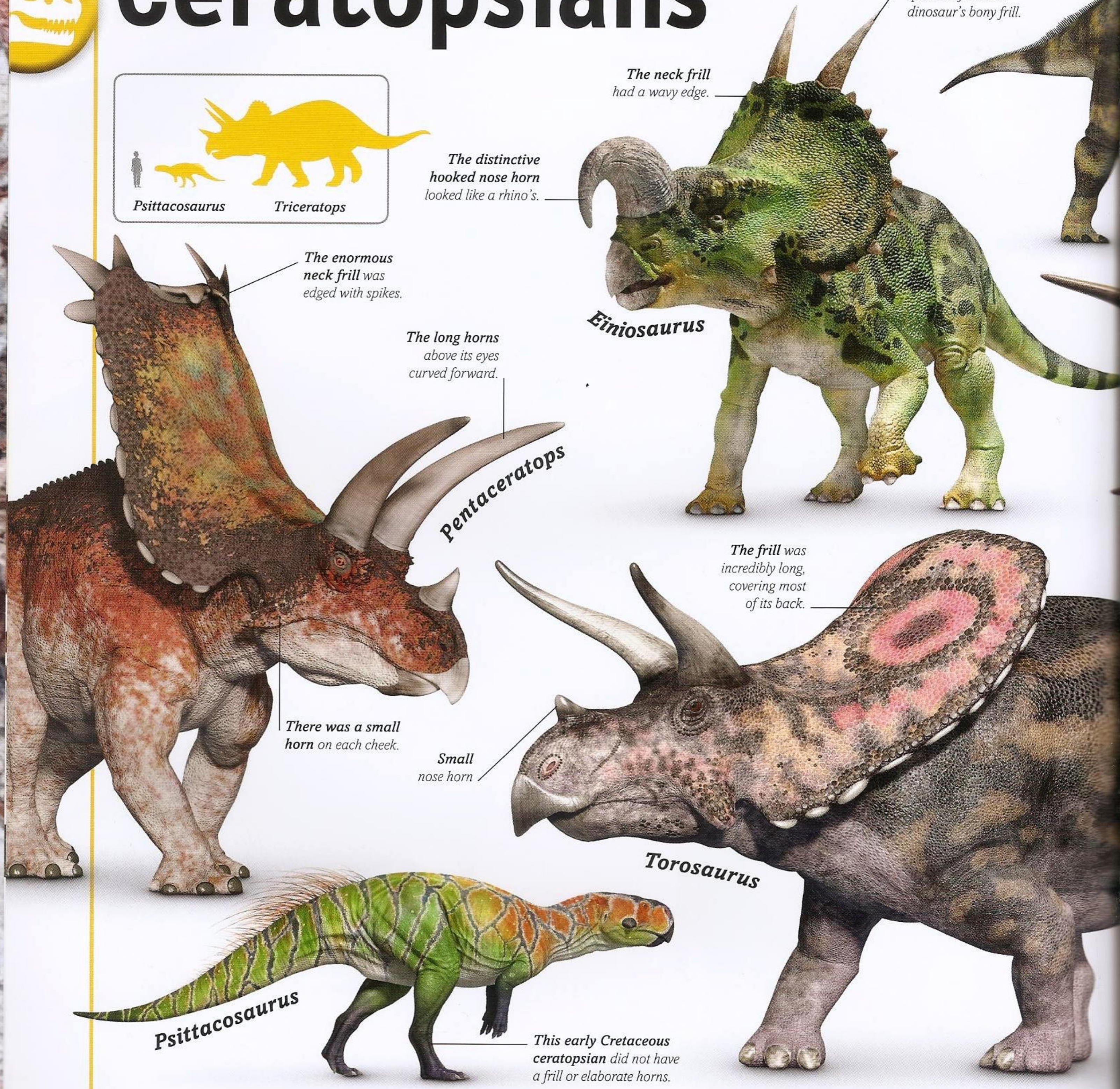
THICK-SKULLED



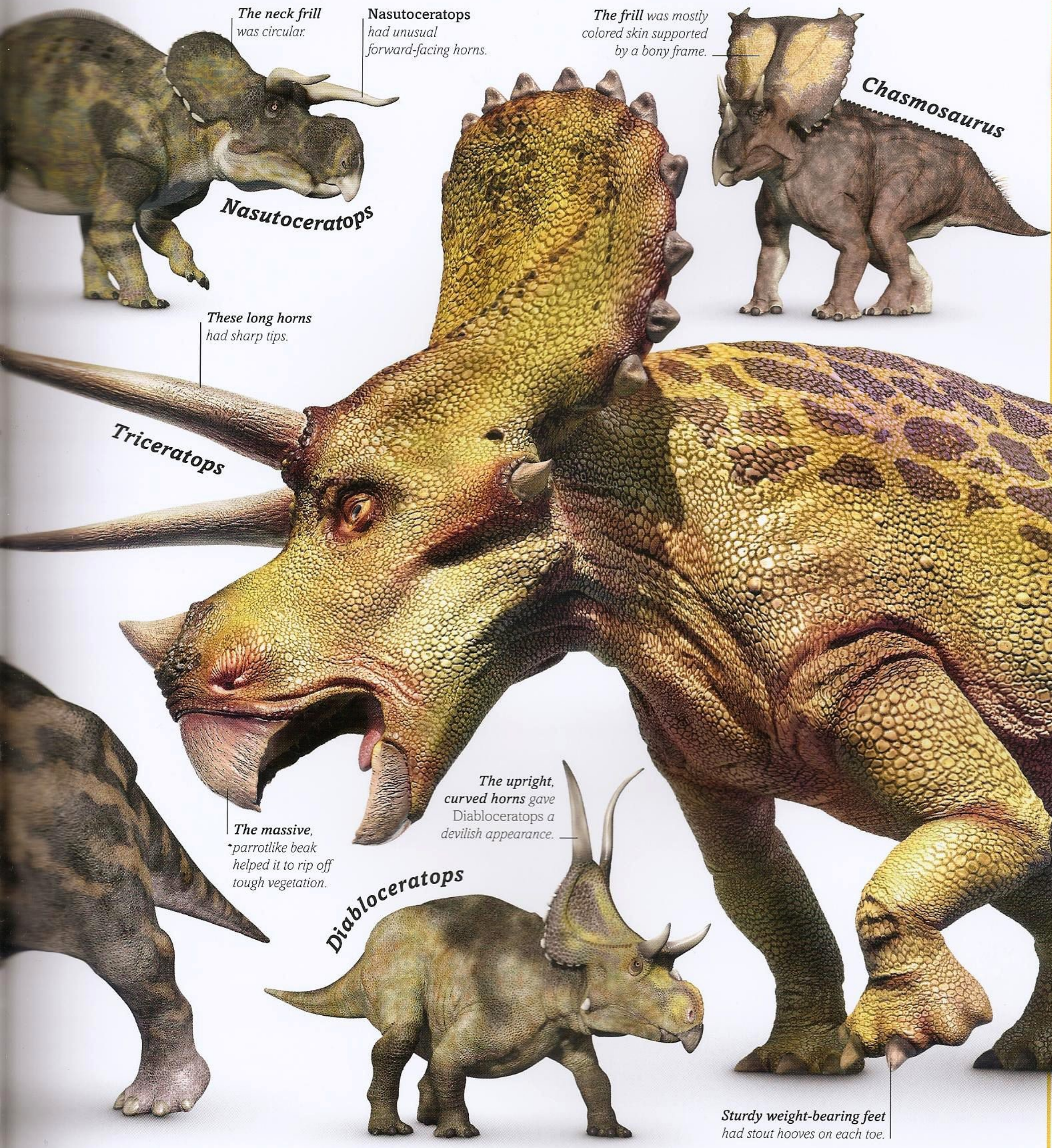
The skull of *Pachycephalosaurus* was 20 times thicker than other dinosaur skulls and cushioned a relatively small brain. The bone often has evidence of damage, supporting the theory that they may have used their skulls for head-butting combats.

and ***Stygimoloch*** had a small dome with much longer horns. But some scientists think these smaller animals are just younger specimens of *Pachycephalosaurus*. Even though the fossil remains of these dinosaurs are very rare, enough have been found to show that pachycephalosaurs were probably fast, agile animals. The fossils also show that they had leaf-shaped teeth like other plant-eating dinosaurs and sharp, pointed teeth at the front of their jaws, suggesting that they may have eaten a variety of plant and animal food.

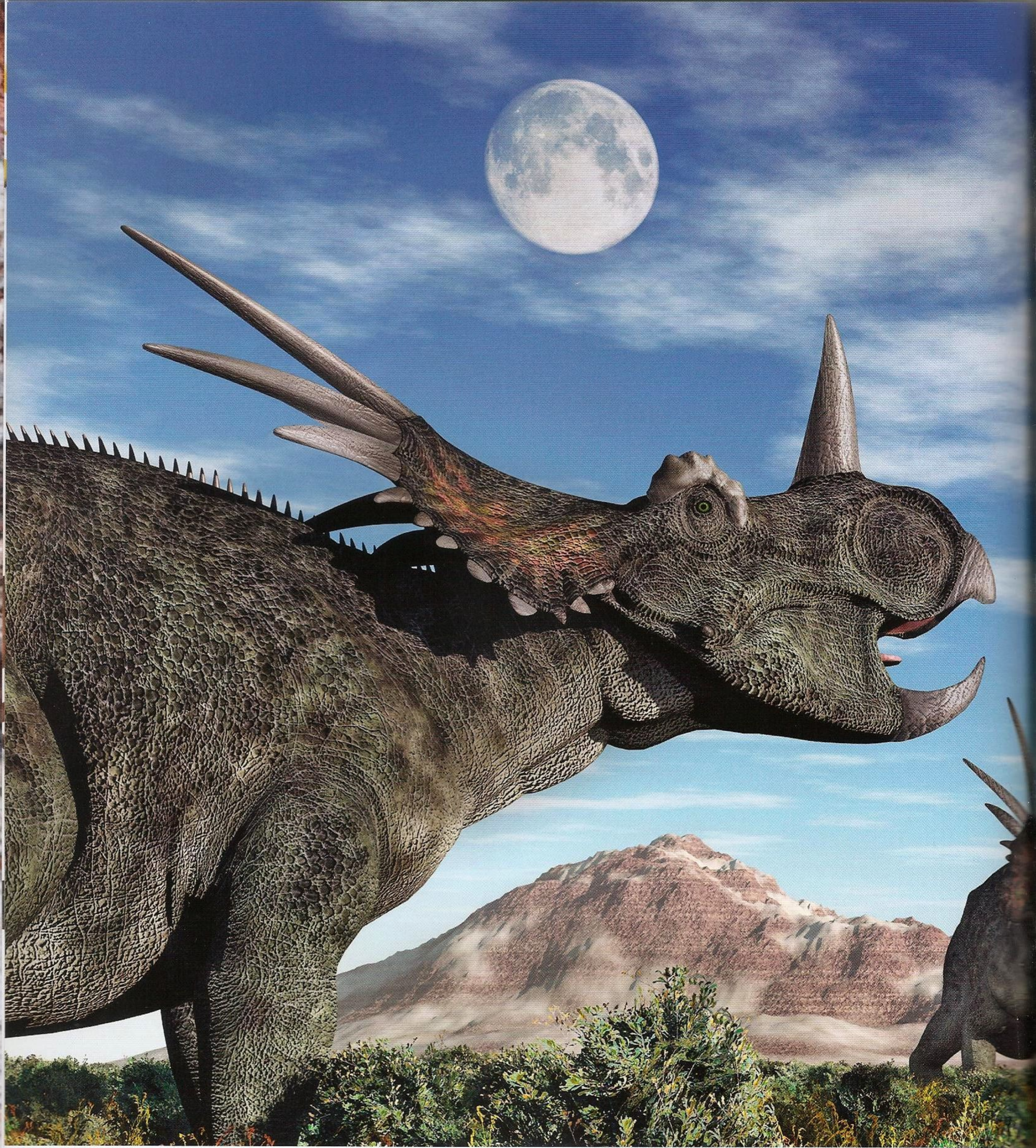
Ceratopsians



With their elaborate neck frills, huge horns, and parrotlike beaks, the ceratopsians were among the most spectacular dinosaurs. The most well-known, ***Triceratops***, was an elephant-sized animal with three horns up to 5 ft (1.5 m) long and a big bony frill extending from the back of its skull. ***Pentaceratops*** was even more flamboyant, with an enormous, probably brightly colored frill fringed by spikes. It evolved from smaller ancestors such as ***Psittacosaurus***, which was light enough to walk on two legs, but the later giants needed all four



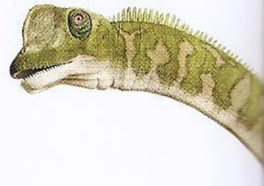
feet to support their weight. The ceratopsians were plant-eaters, equipped with a grasping beak and closely packed teeth that cut through tough leaves like scissors. As with all dinosaurs, the worn-out teeth were continuously replaced by new ones, so their shearing jaws never became blunt. Ceratopsians lived in herds as a possible defense strategy against predators. Fossil evidence suggests they were common in western North America about 74–66 million years ago. *Triceratops* itself was one of the last giant dinosaurs to roam the Earth.



HEAD-TO-HEAD Armed with its enormous nose horn and magnificent spiky frill, Styracosaurus would have been an impressive sight. The size and weight of a rhinoceros, it roamed the forests of North America about 75–74 million years ago, feeding on low-growing plants. Its large frill covered the back of its neck, while six long spikes flared out from the frill.

Styracosaurus lived in the same region and time as the tyrannosaurs *Gorgosaurus* and *Daspletosaurus*—both formidable predators that would have seen it as potential prey. If attacked, *Styracosaurus* may have defended itself with its stout, sharp nose horn. But the dramatic crown around its frill would have had little defensive value, and it probably evolved to impress other dinosaurs of its own species. Males may have competed for territory and mates just like modern bison and deer, and the male with the most imposing array of horns would have had few challengers. But if two rivals were closely matched, they may have fought in head-to-head combat until one backed off in defeat.

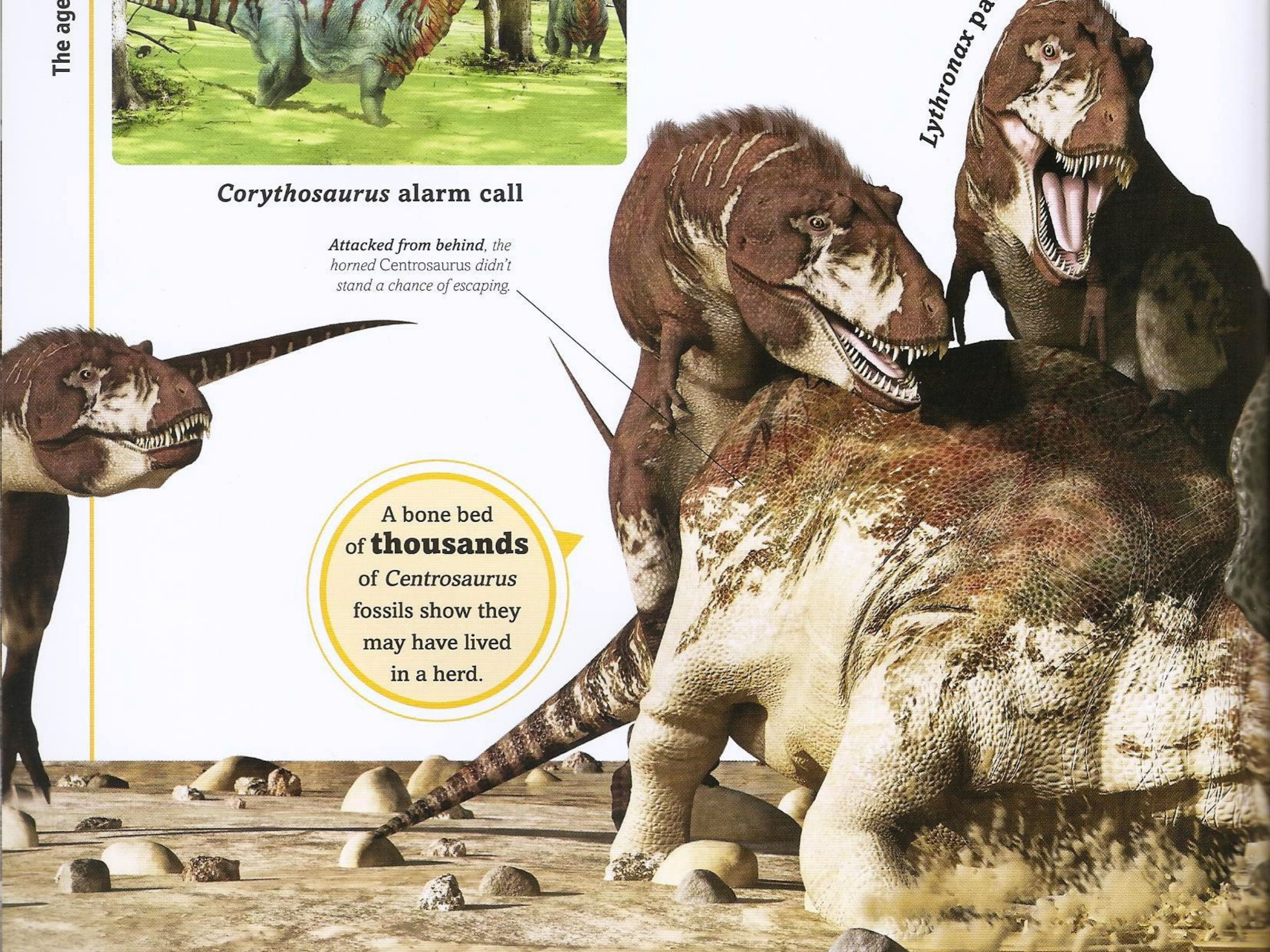
Herds and packs



Corythosaurus may have used air passages *in its crest to make booming calls.*

***Corythosaurus* alarm call**

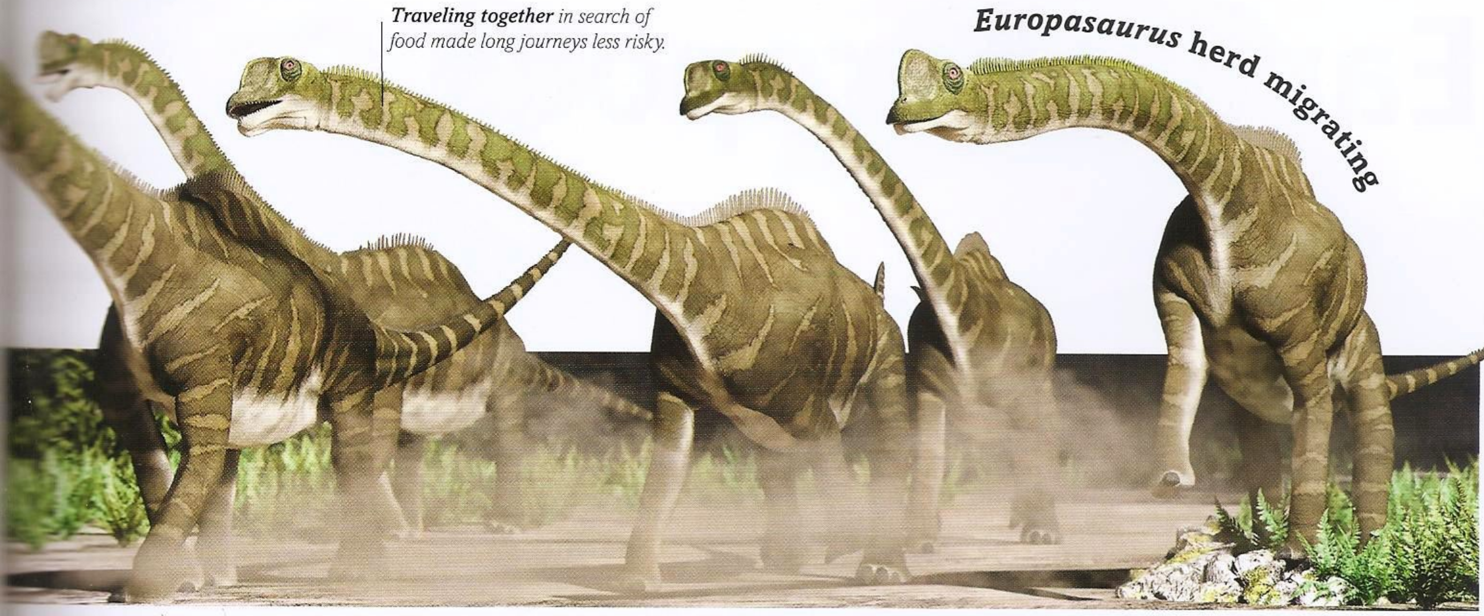
Lythronax pack hunting



***Attacked from behind**, the horned* Centrosaurus *didn't stand a chance of escaping.*

A bone bed of **thousands** of *Centrosaurus* fossils show they may have lived in a herd.

Dinosaurs did not live alone. We know from their fossilized footprints that many traveled in big groups, especially giant sauropods and other plant-eaters. Living in a herd had many advantages for herbivores like ***Corythosaurus***; some animals could concentrate on eating while others kept watch and sounded the alarm if danger threatened. Vulnerable animals could also be protected by several adults, and a dinosaur in a herd was less likely to be targeted than an animal on its own. Some meat-eaters may also have

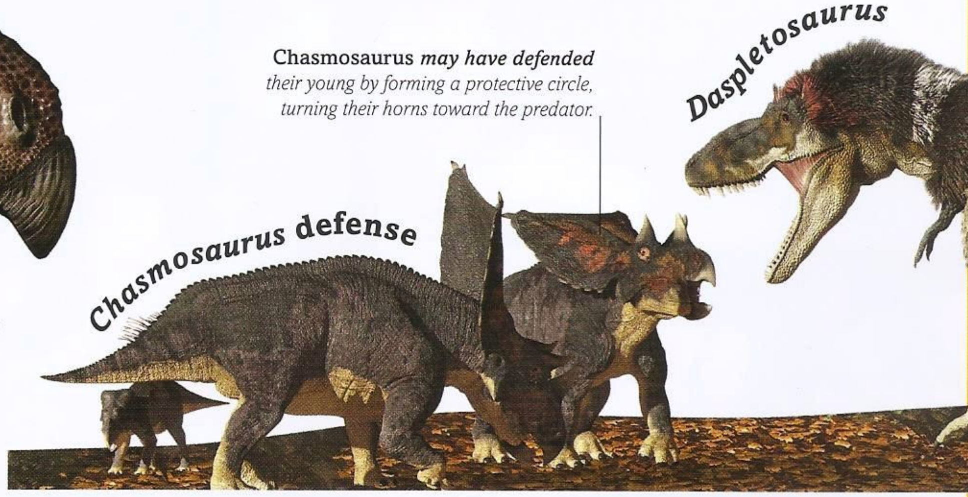


Traveling together *in search of food made long journeys less risky.*

Europasaurus herd migrating

By combining strength, *small hunters could bring down larger prey.*

Deinonychus pack hunting



Chasmosaurus ***may have defended*** *their young by forming a protective circle, turning their horns toward the predator.*

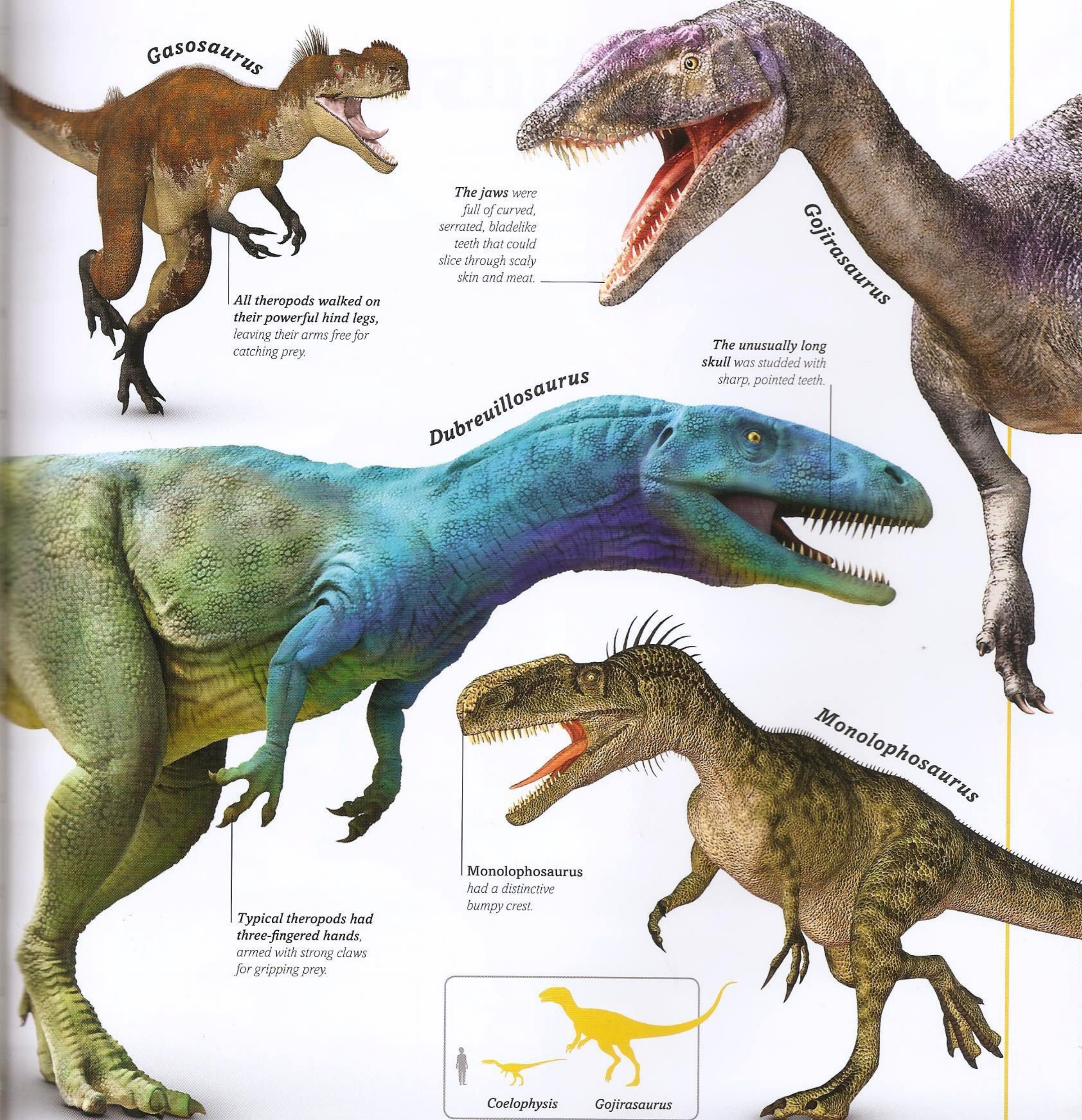
Daspletosaurus

Chasmosaurus defense

lived in groups. While big tyrannosaurs such as ***Daspletosaurus*** probably hunted alone, smaller ones like ***Lythronax*** may have joined forces to bring down larger prey. Several skeletons of the wolf-sized ***Deinonychus*** have been found near the remains of the big, plant-eating *Tenontosaurus*, suggesting that they attacked it in a pack. They were almost certainly not smart enough to devise joint tactics. But they may have learned from experience that they were more likely to get a meal if they all targeted the same victim.

Early theropods

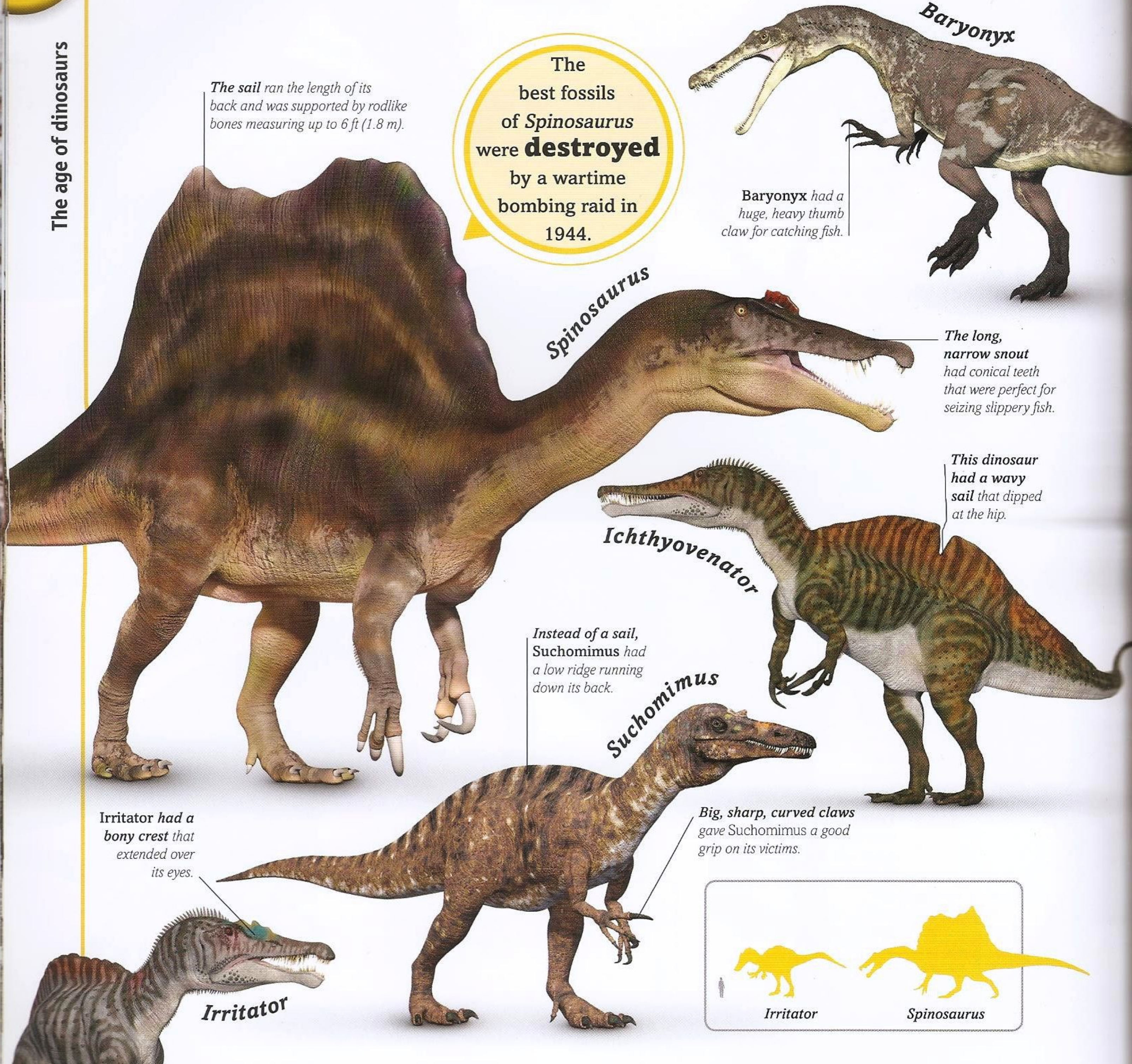
The most powerful, terrifying dinosaurs were those that hunted other dinosaurs. These predators were theropods—animals that ran on two legs, balancing their bodies and typically heavy, strong-jawed skulls with the help of their long tails. They were very successful, evolving into many different types throughout the Mesozoic Era (also known as the age of dinosaurs), and are still thriving today in the form of birds. The first theropods evolved in the late Triassic Period, about 230 million years ago, and were small, lightly built animals. They soon



evolved into slender, agile hunters like ***Coelophysis***, one of the most successful early theropods, and its close relative, the bigger ***Lilienasternus***. Meanwhile, much more powerful hunters were evolving, and by the early to middle Jurassic Period, 200–165 million years ago, there were many big, powerful theropods, including ***Cryolophosaurus*** and the horse-sized ***Dubreuillosaurus***. This period also saw the evolution of the first giant hunters, but the famous, far more heavily armed tyrannosaurs did not appear until much later.

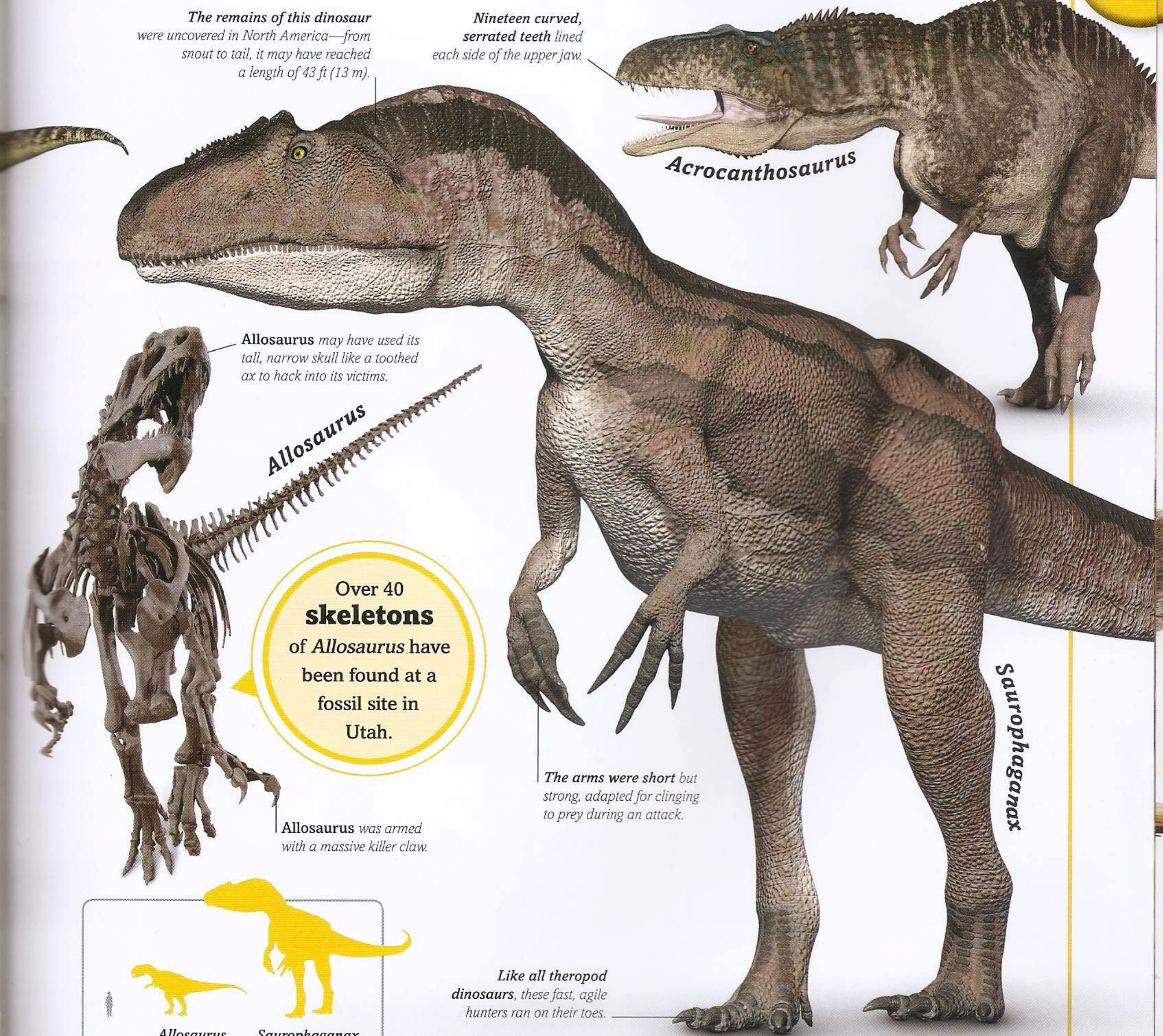
Spinosaurids

The best fossils of *Spinosaurus* were **destroyed** by a wartime bombing raid in 1944.



The biggest predatory dinosaur ever found is the spectacular *Spinosaurus*. At up to 46 ft (14 m) long, this large dinosaur was one of a small group of similar hunters with jaws and teeth that were just like those of a modern crocodile. It is likely that they used them in the same way—to catch big fish in shallow water. But we know that they also ate other dinosaurs, because a fossil of ***Baryonyx*** has been found with the remains of a young *Iguanodon* in its stomach.

Allosauroids



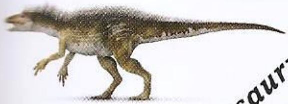
The main enemies of plant-eating dinosaurs during the Jurassic Period were fearsome hunters like *Allosaurus.* This 28 ft (8.5 m) giant had a mouthful of teeth like steak knives, ideal for slicing through flesh. Over time, even bigger predators with the same type of weaponry evolved, including the colossal ***Saurophaganax***. This heavyweight hunter would have been able to overpower gigantic sauropods like the 75-ft- (23-m-) long *Apatosaurus*, whose fossils have been found in the same North American rocks.

Cutting edge

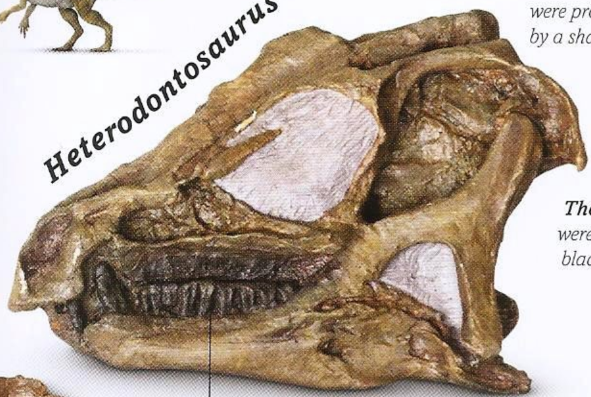
Much of what we know about dinosaurs comes from their teeth. These were constantly replaced, so they never got blunt, and came in all shapes and sizes. The teeth of typical theropods like ***Duriavenator*** clearly belong to a carnivore, or meat-eater, used both as weapons and butchering tools. They were sharp, serrated blades, ideal for inflicting slashing wounds on prey and slicing the meat from their bones. They were useless for chewing, but since meat is easy to digest, mouthfuls could be swallowed without being chewed first.

Struthiomimus

The toothless jaws *were probably covered by a sharp beak.*



Heterodontosaurus



Heterodontosaurus *had long canine teeth at the front but flattened chewing teeth at the back.*

Tyrannosaurus

The massive, spiked teeth *were stronger than the slender blades of typical meat-eaters.*

These thick, strong teeth *were used for cracking through bone.*

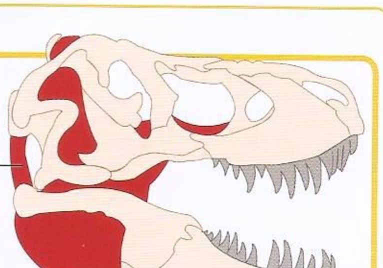
Daspletosaurus

The teeth *were rooted in big jaw bones, strong enough to cope with struggling prey.*

Duriavenator

JAW MOVEMENT

Meat-eating dinosaurs did not have to chew their food, so their jaws did not need to move in complex ways to grind their teeth together. But the jaws did need to be strong—especially those of bone-crunching tyrannosaurs, which were equipped with huge muscles to give them a massively powerful bite.

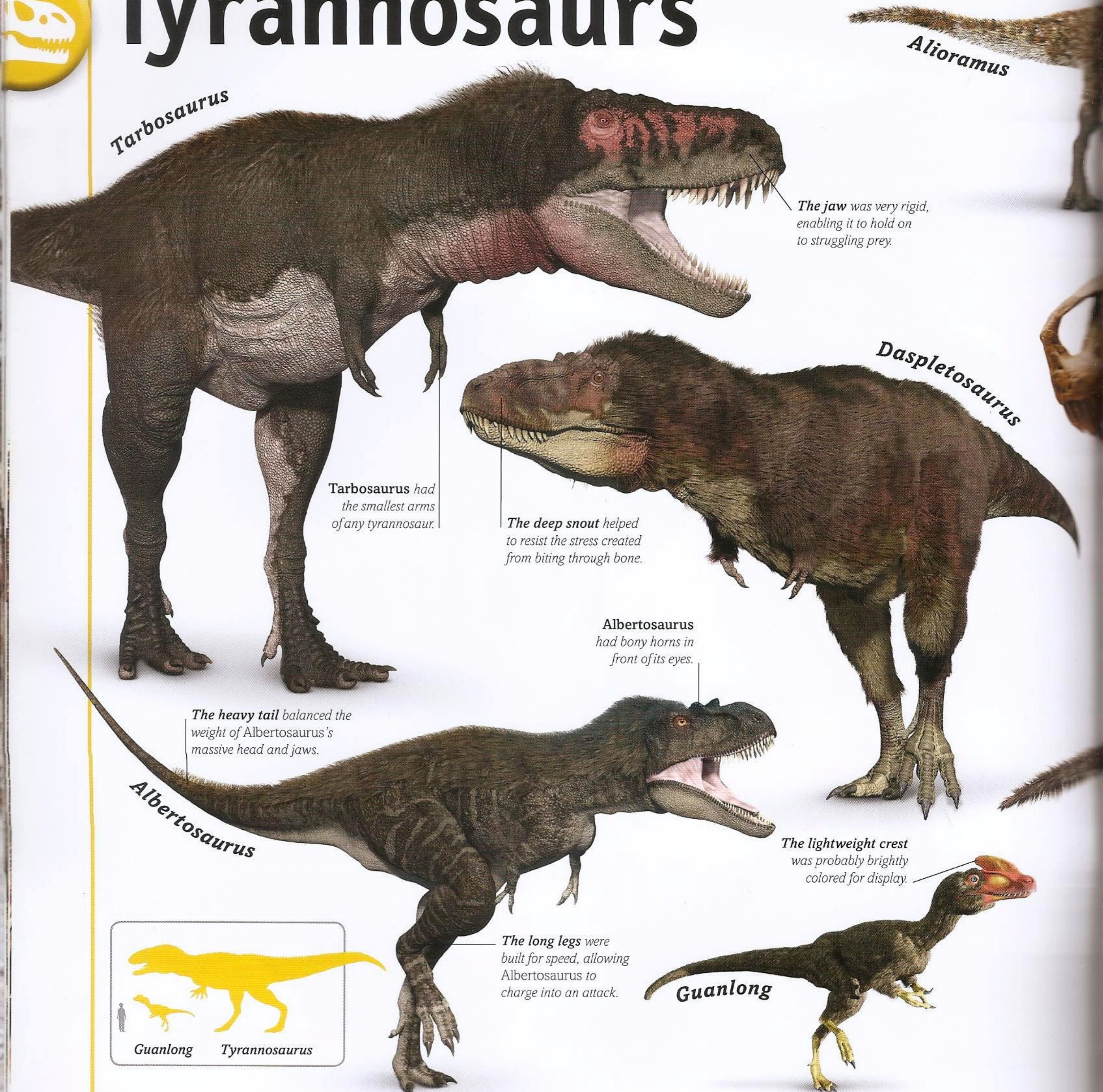


These small muscles opened the jaw.

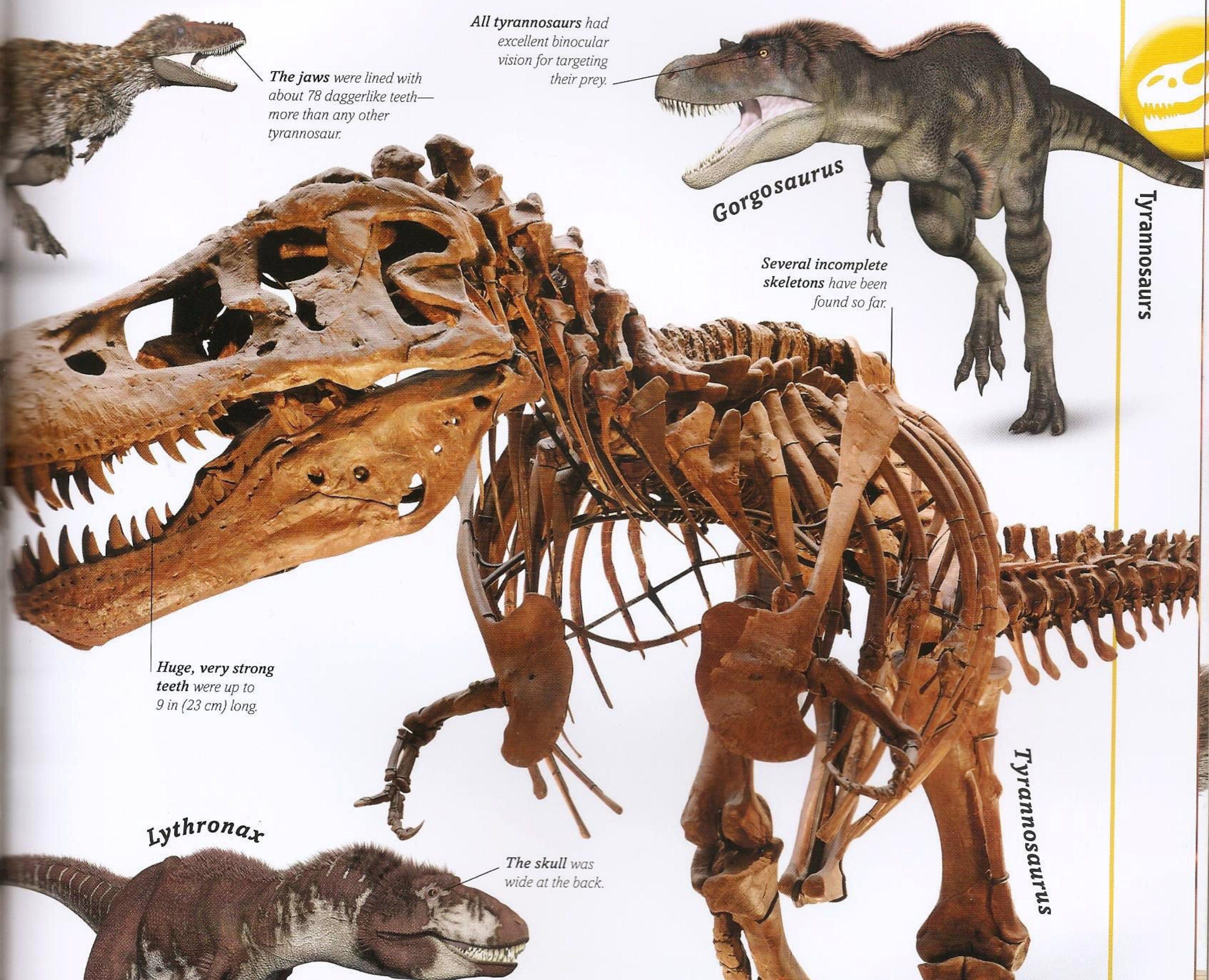
The jaw was snapped shut by very big muscles.

Different types of teeth suited different types of prey. ***Velociraptor*** had bladelike teeth, ideal for attacking and eating other dinosaurs, but the pointed teeth in the jaws of ***Baryonyx*** were adapted for catching slippery fish. The massive spikes of ***Tyrannosaurus*** were perfect for biting through bone, while the birdlike ***Struthiomimus*** had no teeth at all. It may have eaten plants, small animals, or both. Unusually, ***Heterodontosaurus*** had several different types of teeth, which may have enabled it to eat both animals and plants.

Tyrannosaurs

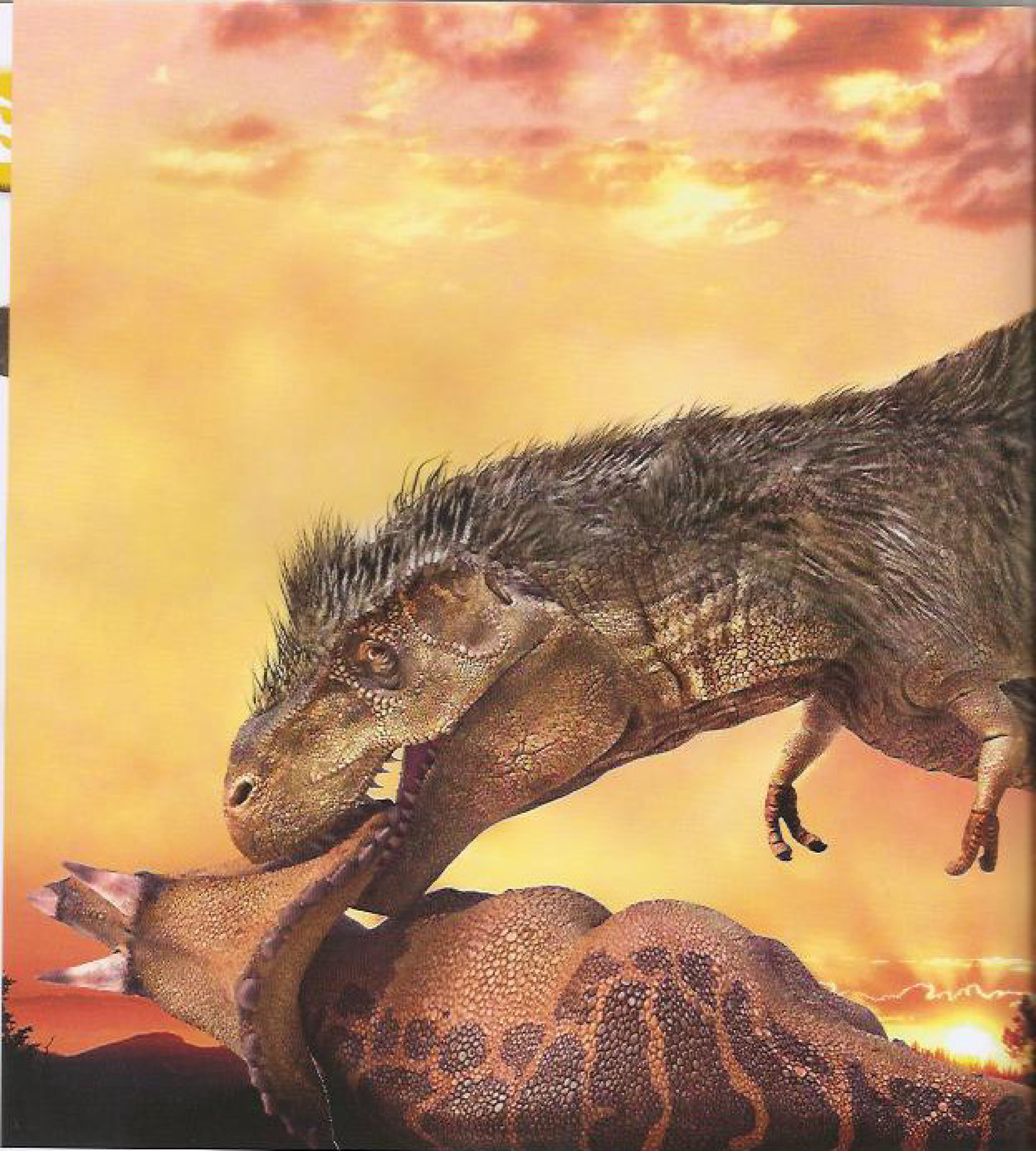


The tyrannosaurs ("tyrant lizards") were the most powerful land predators to walk the Earth. These theropods first appeared about 160 million years ago and thrived until the age of the dinosaurs came to an end 66 million years ago. The biggest of them all was ***Tyrannosaurus***—the ultimate heavyweight killer. Their weapons were their specialized teeth. Unlike other theropods, which had mouths full of sharp but fragile, knifelike teeth, the tyrannosaurs had stout spikes backed by powerful jaw muscles. This gave them the strength to bite straight

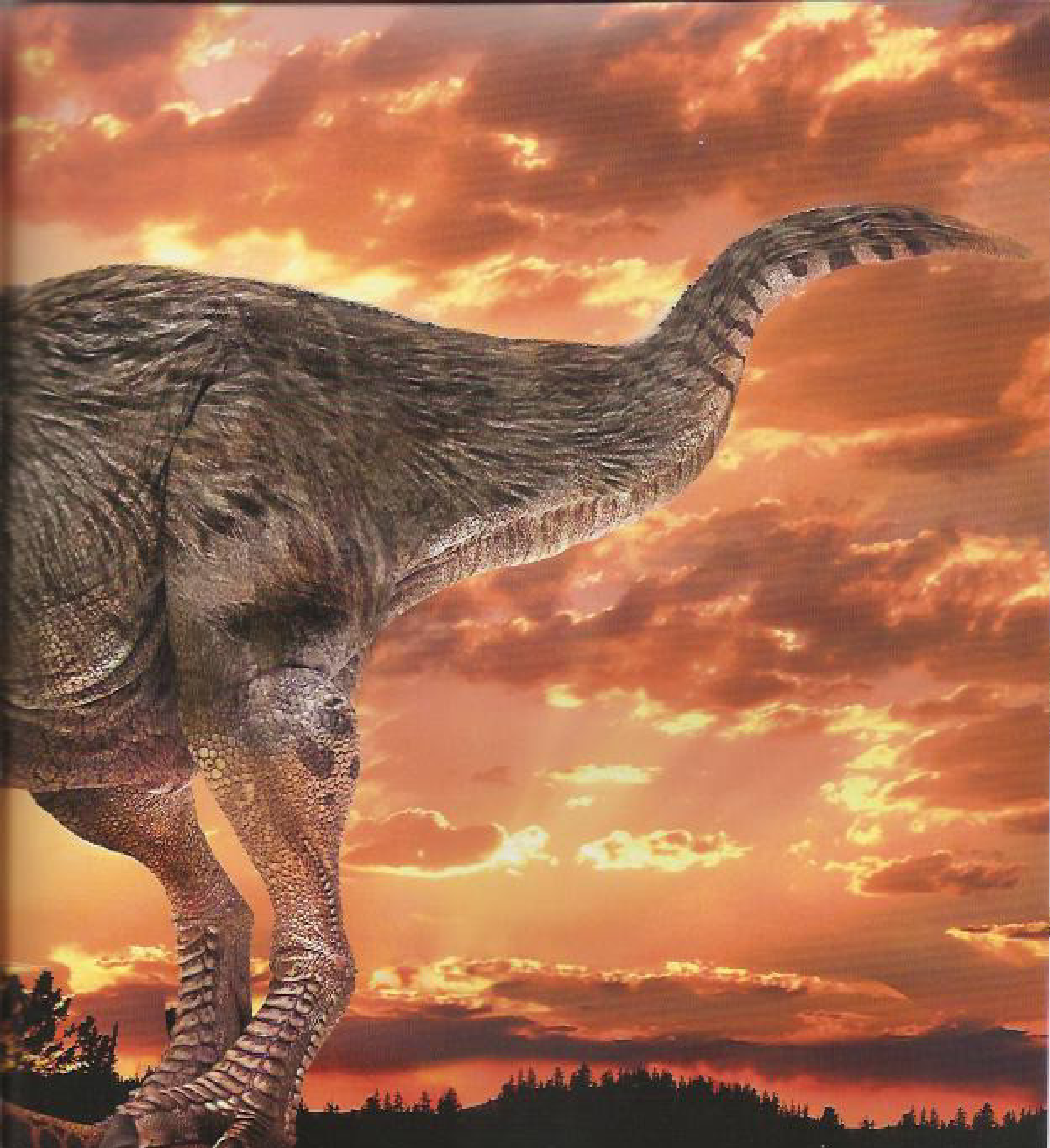


Fossilized *Tyrannosaurus* dung is full of bone fragments, proving it could **crush bone.**

through bone and enabled them to kill armored prey that other predators dared not attack. Their jaws were so deadly that they did not need strong hands to grip their victims, and their arms were tiny compared to their long, muscular legs. Some of the earlier tyrannosaurs were more lightly built, including ***Alioramus*** and ***Lythronax***, while others like ***Guanlong*** had crests on their heads. But all the ones that came later had a similar body structure—massive heads with a huge set of jaws mounted on a pair of powerful legs.



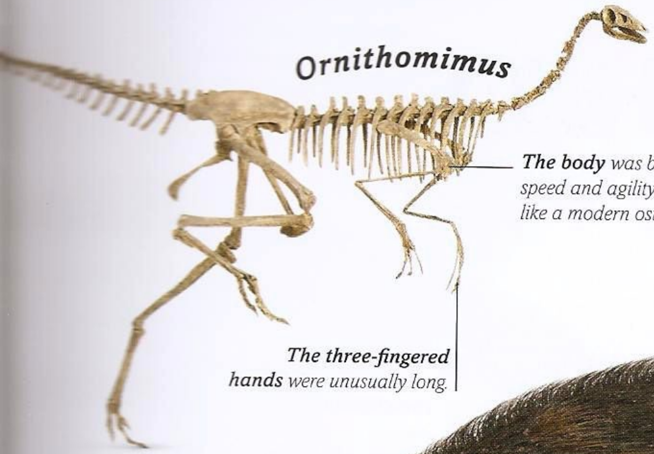
ULTIMATE HUNTER *Tyrannosaurus* was one of the last of the giant dinosaurs, and one of the most lethal. Armed with huge bone-crushing teeth and immense jaws that could inflict crippling bites, it was the top predator of its time. The strength of its bite was greater than that of almost any other predator in history, enabling it to subdue even elephant-sized animals such as this *Triceratops*.



Tyrannosaurus had a simple but effective technique when it came to attacking prey—it would charge straight in, sink its teeth into its target, and use its strong jaw and neck muscles to rip away mouthfuls of flesh and bone. Stunned by blood loss, the victim would not try to struggle free. So, *Tyrannosaurus* did not need to cling on to prevent its escape. Since strong forelimbs were not needed, they were reduced to tiny arms that couldn't even reach its mouth. By contrast, its legs were built like those of a racehorse, with massive thigh muscles and long, slender lower limbs. So, despite its immense weight, *Tyrannosaurus* would have launched its attacks with deadly speed.

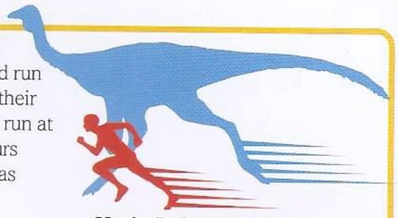
Ornithomimosaurs

The powerful, heavy-jawed tyrannosaurs had some close relatives that could hardly look less like them—the ornithomimosaurs. These included animals like ***Struthiomimus***, which means "ostrich mimic," and they certainly resembled ostriches in many ways. Most ornithomimosaurs had small heads with toothless beaks; long necks; winglike arms with fluffy feathers; and long, muscular back legs. They probably even had a similar diet of seeds, fruits, and small animals, although some had broader beaks that they may have used for dabbling in



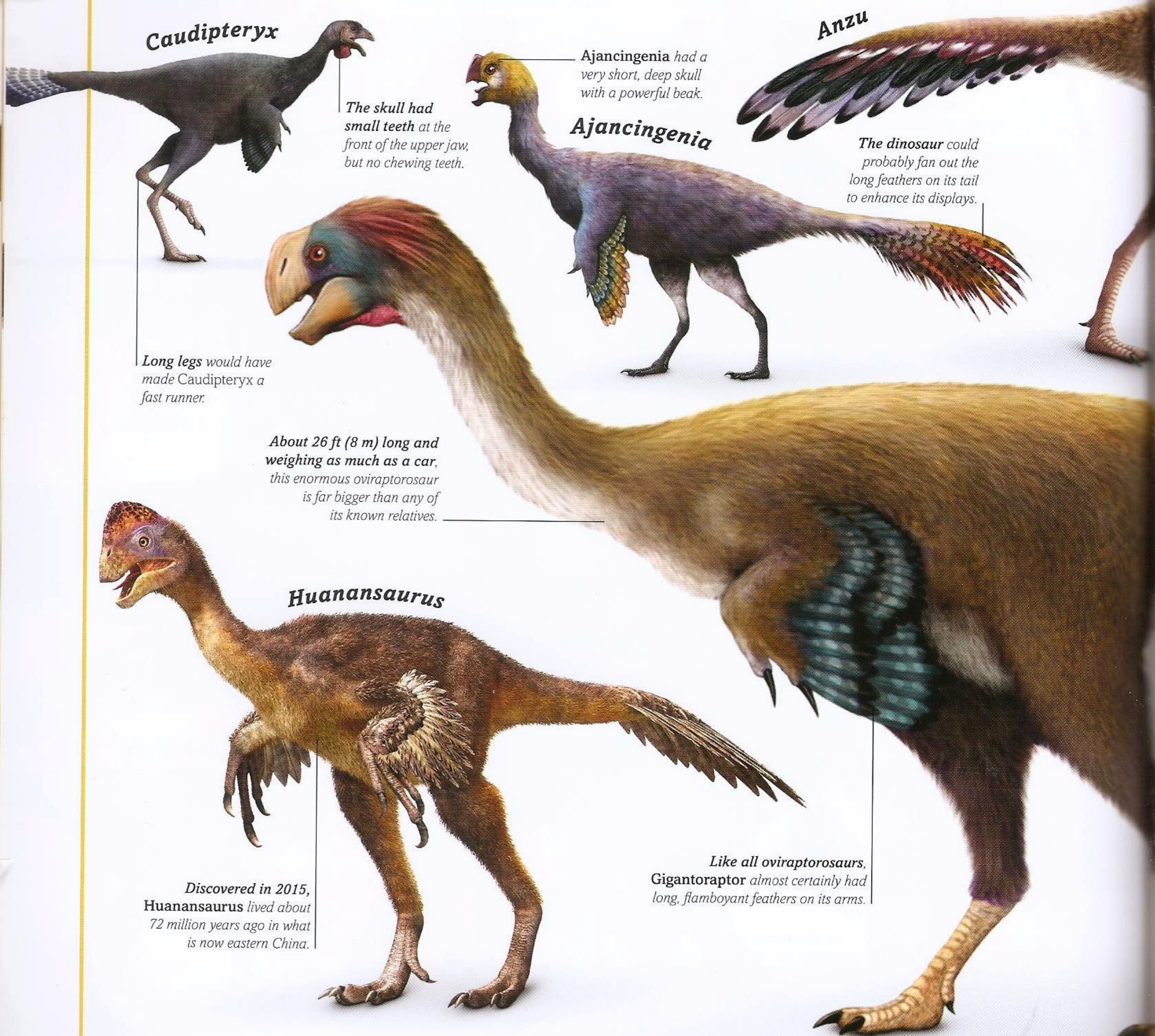
SPEEDSTERS

Long-legged ornithomimosaurs could run very fast. Recent studies show that their biggest enemies, tyrannosaurs, could run at 19 mph (30 kph), so ornithomimosaurs probably ran faster—maybe as fast as Jamaican athlete Usain Bolt, who reached 27 mph (44 kph) in 2009.



the water like ducks. But not all ornithomimosaurs were toothless or ostrich-sized. Some of the early types had jaws studded with small teeth, and some of the later ones like ***Beishanlong*** were big, powerful animals. The biggest found so far was ***Deinocheirus***, a giant that grew to 36 ft (11 m) long and had very long arms and hands. Relative to its body, it had shorter legs than other ornithomimosaurs, so it probably relied on its size and big defensive claws to discourage the powerful predators of its time and make them look for softer targets.

Oviraptorosaurs

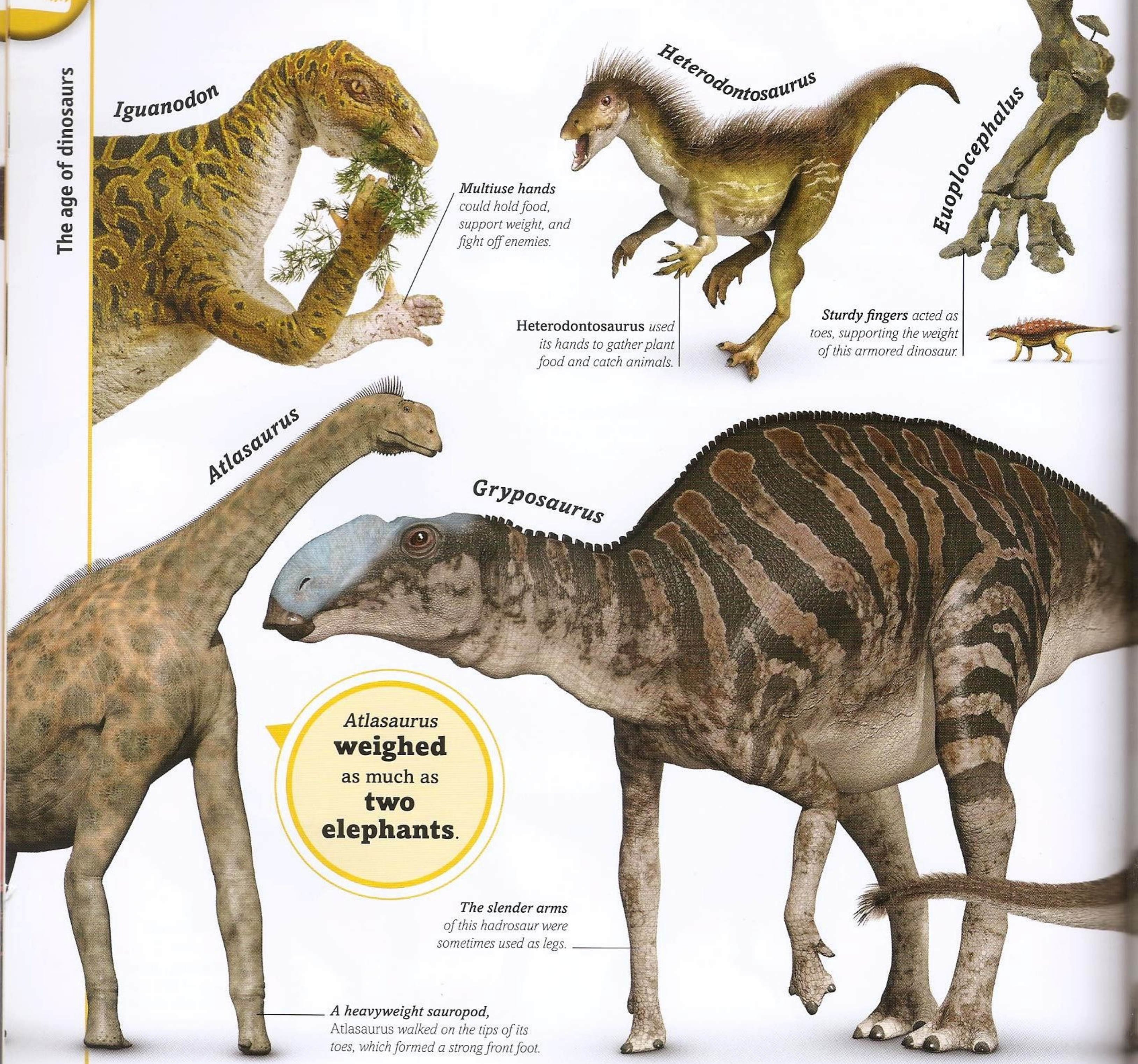


In 1923, a group of American fossil hunters in Mongolia discovered the first complete dinosaur eggs. They also found the skull of an odd-looking dinosaur close by. They assumed it was trying to eat the eggs and called the dinosaur ***Oviraptor***, which means "egg thief."

Much later, in the 1990s, it became clear that the eggs were its own and that it was actually looking after them. Despite this, the name stuck and is now used to describe several animals with the same features—the oviraptorosaurs. They belonged to a group

of typically long-armed theropod dinosaurs called the maniraptorans, which also includes the birds. The maniraptorans probably all had feathery bodies and tails and long feathers on their arms. Oviraptorosaurs also had birdlike, often toothless beaks, which they may have used to gather a wide range of food, including seeds, big insects, lizards, small mammals, and possibly even the eggs of other dinosaurs. They had two bony projections on the roof of the mouth that would have been ideal for cracking eggshells, so maybe they were egg thieves after all.

Arms and hands



The arms and hands of dinosaurs evolved in different ways to perform a variety of tasks. Those of small plant-eaters were adapted for gathering food, but many, like ***Iguanodon***, used their hands to support their weight. Bigger plant-eaters had very stout forelimbs that were specialized for walking. The arms of typical meat-eaters like the powerful ***Dubreuillosaurus*** were adapted for gripping struggling prey while the predator got to work with its jaws. They were short but strong, with sharp claws. Over time, some hunters, such as ***Citipati*** and

GIANT ARMS

The enormous hands of this dinosaur earned it the name *Deinocheirus*, which is Greek for "horrible hand." The arms were 8 ft (2.5 m) long and ended in hands that were about 2½ ft (76 cm) long.

The three-fingered hand had huge, blunt claws.

Sinornithosaurus, developed much longer arms and hands. These were often used in the same way, but recent fossil evidence shows that they carried long feathers, almost like wings, and *Citipati* used these to shelter its eggs and young. Relatives of these animals had even longer feathered arms, and they became the first birds. By contrast, some very powerful hunters, including ***Carnotaurus*** and the tyrannosaurs, evolved very short arms and relied on their jaws to subdue prey.

PROTECTIVE WINGS

Seventy-five million years ago, the deserts of southern Mongolia were just as dry as they are today, with extensive sand dunes and few rivers. Despite this, they were home to several dinosaurs. They included the ostrichlike *Citipati*—famous among scientists for their amazing fossils, which show that these dinosaurs incubated their eggs like birds.

Like many other theropods, *Citipati* had long arms equipped with feathers similar to the flight feathers of bird wings. But *Citipati* clearly could not fly, because its "wings" were far too short. The feathers must have had another function, and several fossils found in the Gobi Desert show what that might have been. The animals are preserved crouching on top of clutches of eggs, with their arms spread out to the edges of the nest. In this position, their long feathers would have covered the eggs, keeping them warm or shading them from the scorching desert sunshine. But feathers could not protect *Citipati* and its eggs from whatever killed, buried, and preserved them as fossils beneath the desert sand.

Therizinosaurs

Most theropods were sharp-toothed, agile hunters, but the therizinosaurs were different. Very few complete fossils have been found, but when paleontologists pieced together the evidence, therizinosaurs turned out to be unusual. They had beaked jaws, leaf-shaped cheek teeth, and bulky bodies, suggesting that they probably fed on plants instead of hunting prey. They were long-armed members of the maniraptorans—a group of theropods related to birds—and like them, were feathered. But the feathers seem to have been reduced to slender

filaments, making therizinosaurs like ***Erlikosaurus*** look as though they had dense fur. Their long arms had big hands equipped with huge claws—those of the giant ***Therizinosaurus*** are the longest claws of any known animal. The therizinosaurs may have used their claws to haul leafy branches within reach of their mouths. But they could also have used their claws as formidable weapons against predators. With their bulky bodies, therizinosaurs could not move quickly, so fighting may have been their best form of self-defense.

Sharp claws

Baryonyx means "heavy claw," which refers to the **curved claw** on its index finger.

Strong claws were essential tools for most dinosaurs. Like many hunters, ***Allosaurus*** and ***Baryonyx*** used the claws on their forelimbs to seize prey, while ***Deinonychus*** had foot claws that were specialized for pinning prey to the ground. Most predators had strong but sharp foot claws that gave them the grip needed for running, and some of the smaller, birdlike hunters may have used their claws to climb trees. Gigantic four-footed plant-eaters such as ***Apatosaurus*** had stout claws that helped support their colossal weight, but they also may

This plant-eater used its long sharp claw to dig up roots.

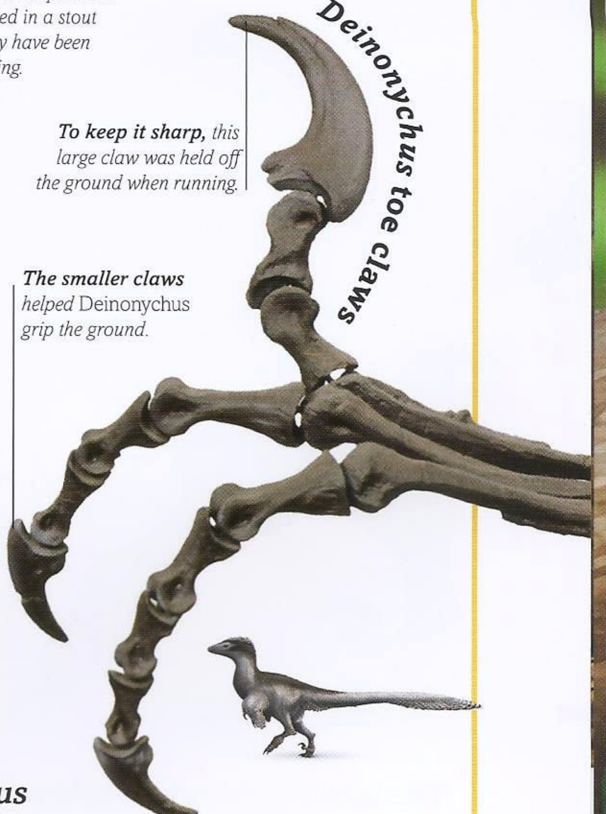
Each hand had three claws for gathering food.

Scientists think Oviraptor may have used its hand claw to hold on to its prey.

The thumb spike was used for defense.

The thumb on the pillarlike front legs ended in a stout claw and may have been used for digging.

The fish-eating Baryonyx would have used its large curved claw to seize slippery fish.

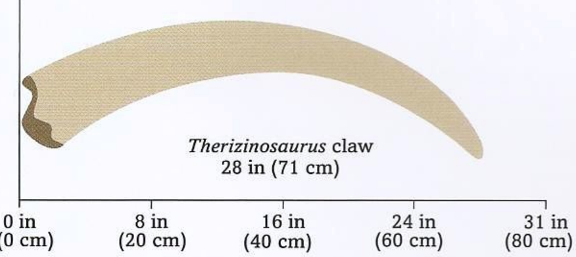


To keep it sharp, this large claw was held off the ground when running.

The smaller claws helped Deinonychus grip the ground.

FORMIDABLE CLAWS

The claws of the plant-eating *Therizinosaurus* were about 28 in (71 cm) long—the longest claws ever known. The points and edges of the claws would have been sharp enough to inflict serious injuries.

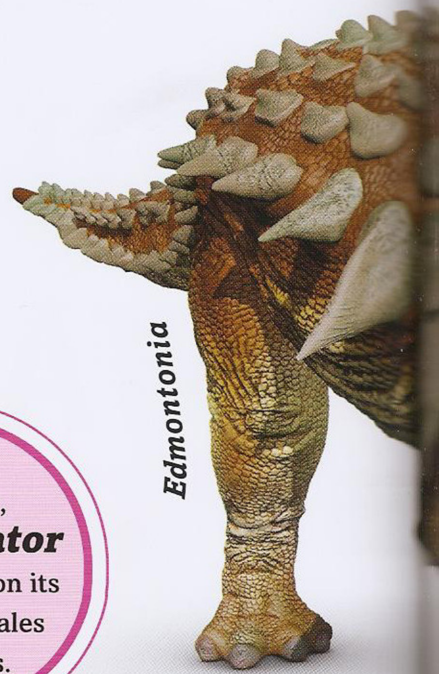


have used them to dig holes where they laid their eggs. ***Plateosaurus*** stood on its hind legs and used its front claws to gather food from trees or, more vitally, defend itself from predators. ***Iguanodon*** had a stout thumb spike, which it may have used against its enemies, while ***Therizinosaurus*** had astonishingly long claws on its forelimbs that would have been lethal weapons, ideal for defense against some of the most powerful predators that ever existed.

Skin, scales, and feathers

Archaeopteryx

Long feathers *on its extended arms almost certainly gave this Jurassic dinosaur the ability to fly.*



Edmontonia

Like a chicken, ***Juravenator*** had feathers on its body and scales on its legs.

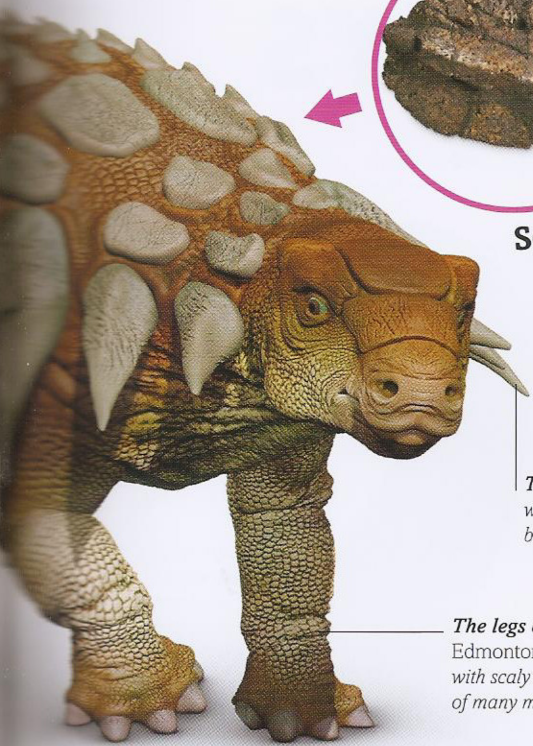
Juravenator

The furry body covering *of this small theropod dinosaur was made up of simple, hairlike protofeathers.*

Edmontosaurus skin fossil

This fossil *shows that the skin of* Edmontosaurus *was protected by small scales.*

Most extinct dinosaurs are known only from fossils of their bones and teeth, but some fossils also preserve details of soft tissues, such as skin. They show that many large dinosaurs like the hadrosaur ***Edmontosaurus*** had scaly skin, and some, such as ***Edmontonia***, had a type of armor formed from plates of bone (scutes) embedded in the skin. Amazing fossils discovered recently in China have revealed that many small theropod dinosaurs had feathers. Some, like ***Sinosauropteryx***, had short, slender filaments,



Scute

The fossilized feathers *of* Caihong *include microscopic structures like the melanosomes that create iridescent feather colors in some modern birds.*

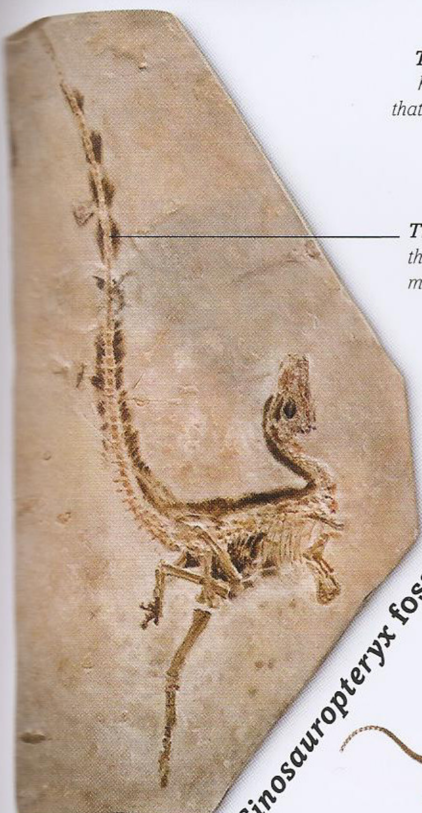
This armored dinosaur's scutes *were spike-shaped, partly for defense but perhaps also for show.*

Caihong

The legs and belly *of* Edmontonia *were covered with scaly skin, similar to that of many modern reptiles.*

***Psittacosaurus* fossil**

This fossil *of an early relative of the horned dinosaur* Triceratops *shows that its tail was covered with long quills.*

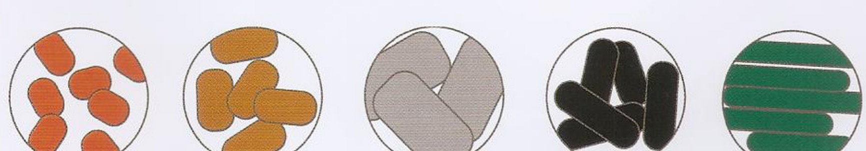


The dark patches on this fossil *are the remains of a fuzzy body covering made up of protofeathers.*

***Sinosauropteryx* fossil**

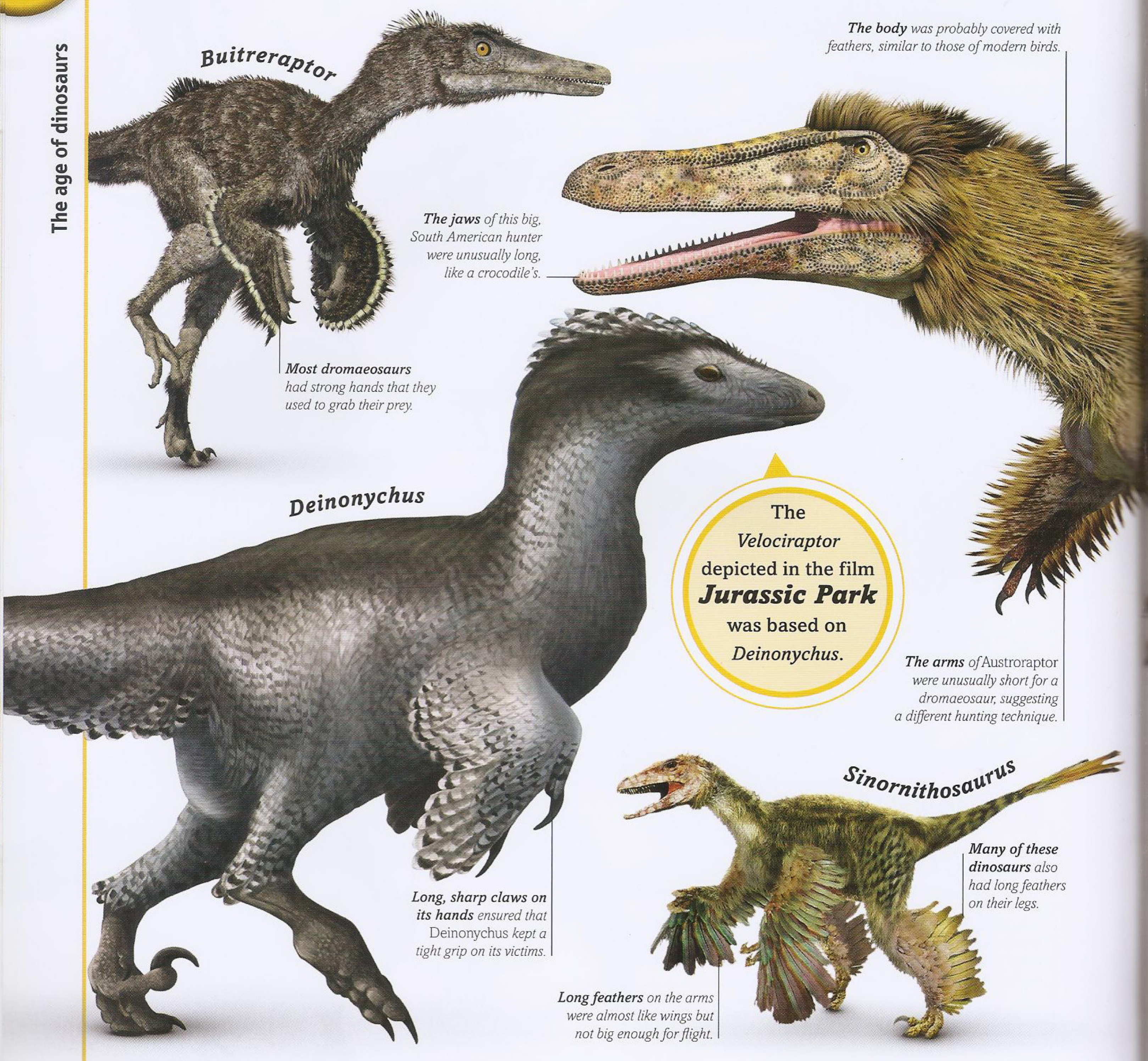
COLOR CODING

New research has revealed that the fossil feathers of animals like *Caihong* preserve the remains of melanosomes—structures inside cells that contain color pigments. The size, shape, and arrangement of these melanosomes are related to their color. So by analyzing fossil melanosomes, scientists may be able to reconstruct the colors of feathered dinosaurs.



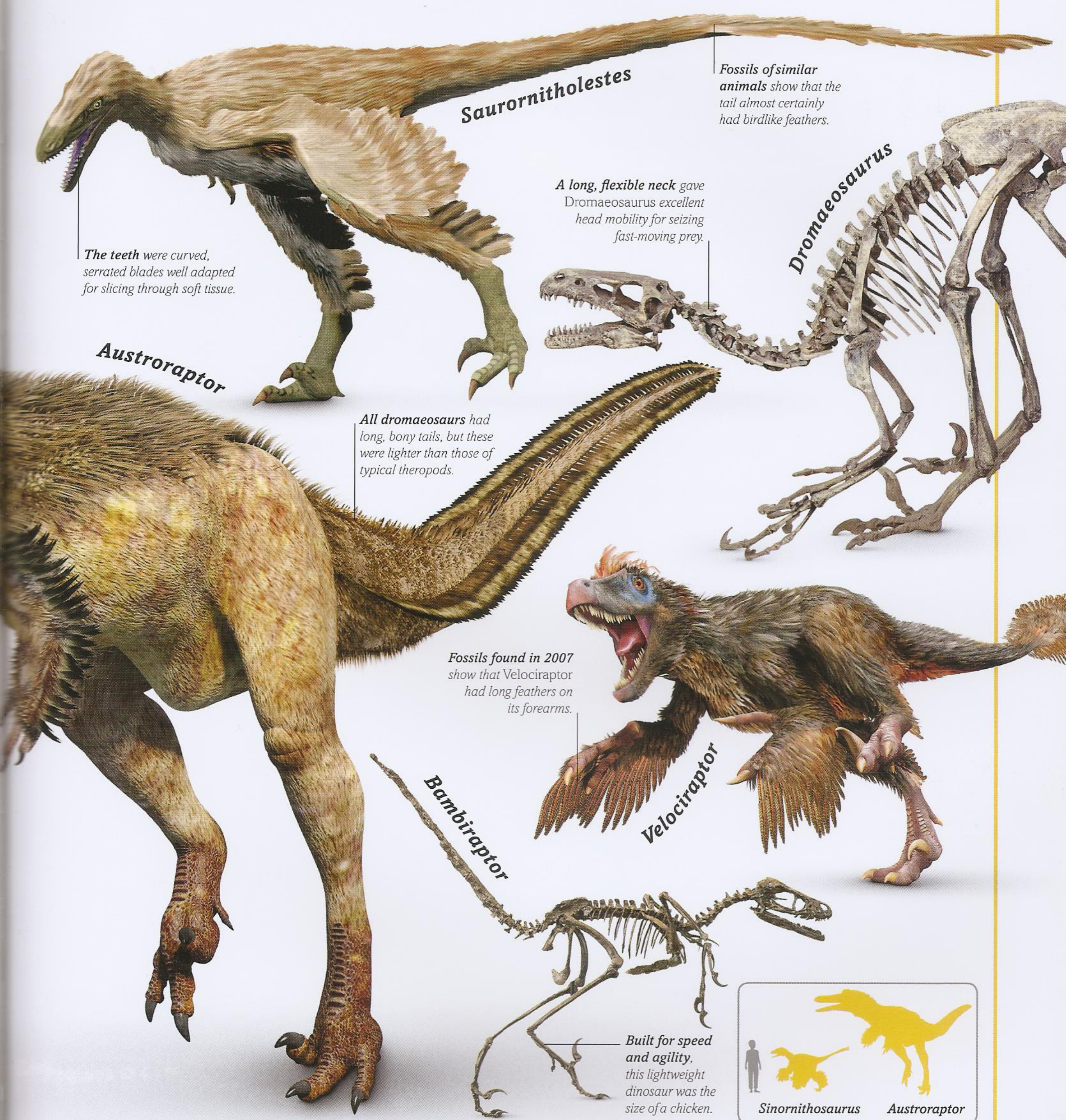
or protofeathers, resembling hair; these probably kept the animal warm, like the fur of a mammal. Others, including ***Caihong***, had fully vaned feathers, like those of modern birds. Some of these feathers were longer, especially on the arms, which would have looked like short wings. Microscopic analysis even indicates that some of the feathers were brightly colored. All this new evidence shows that there is little difference between these extinct theropod dinosaurs and living birds and supports the conclusion that birds are small, flying dinosaurs.

Dromaeosaurs



The *Velociraptor* depicted in the film ***Jurassic Park*** was based on *Deinonychus*.

The most well-known lightweight hunters of the dinosaur age are the dromaeosaurs, often called raptor dinosaurs after animals like the small, agile *Velociraptor*. They were typically long-armed hunters with large claws on their hands. The second toe on each foot had an oversized, hooked claw that was held off the ground to keep it sharp. This specialized claw was probably used to pin prey to the ground, or even—in smaller types—to climb trees. Recent fossils found in China show that these dinosaurs were covered in feathers, and many had long,

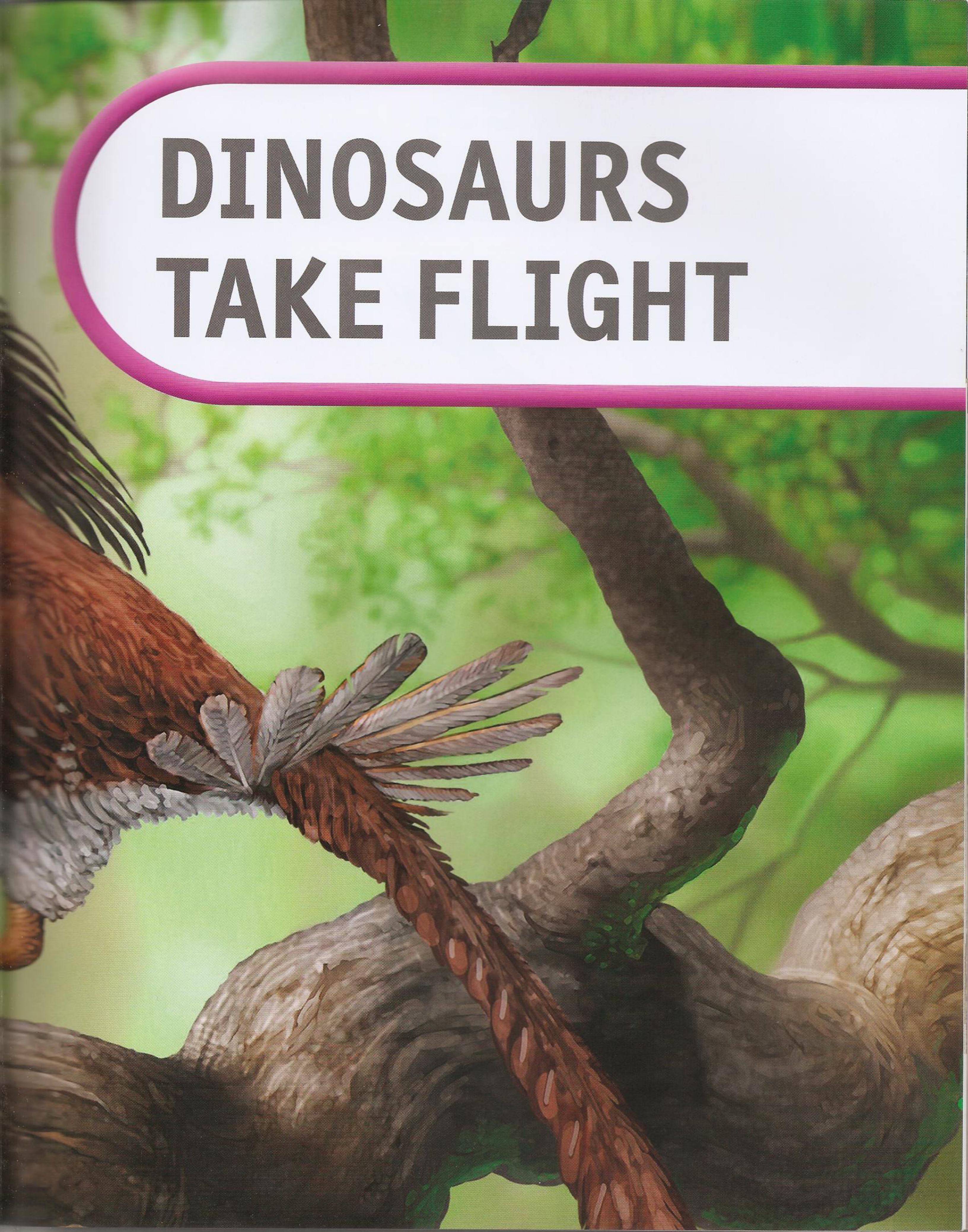


almost winglike feathers on their arms. They were closely related to the first birds, and the smallest ones—animals like ***Sinornithosaurus***—would have looked very birdlike. Small dromaeosaurs would have preyed on big insects and small ratlike mammals, but we know that the bigger ones, including *Velociraptor* and **Deinonychus**, attacked other dinosaurs. Some, such as **Buitreraptor** and the unusually large ***Austroraptor***, had long snouts filled with pointed, conical teeth that were more suited to catching fish.

TOOTHED EAGLE When the first fossils of *Velociraptor* were found in Mongolia in the 1920s, it was imagined as a scaly, lizardlike animal. But fossils of a closely related dinosaur discovered in nearby China show that *Velociraptor* would have looked more like a bird. A row of bumps on one of its forearm bones also shows that its arms carried long feathers very like those of a bird's wing.

Even the behavior of *Velociraptor* was probably birdlike. Related dinosaurs laid their eggs in nests and sat on the eggs to keep them warm, using their "wings" to shelter them. *Velociraptor* almost certainly nested like this, perhaps in pairs, and while one of the pair brooded the eggs, the other would go hunting. Recent research into how *Velociraptor* hunted suggests that it ran after its prey and pounced on them like a flightless eagle, pinning animals to the ground with the special, enlarged claws on its feet. The hunter would then tear into its unlucky victim with its sharp-edged, serrated teeth, ripping it to pieces. It may even have taken some of the meat back to the nest for its mate.

DINOSAURS TAKE FLIGHT



Skin, scales, and feathers

Archaeopteryx

Long feathers on its extended arms almost certainly gave this Jurassic dinosaur the ability to fly.

Like a chicken, ***Juravenator*** had feathers on its body and scales on its legs.

Edmontonia

Juravenator

The furry body covering of this small theropod dinosaur was made up of simple, hairlike protofeathers.

Edmontosaurus skin fossil

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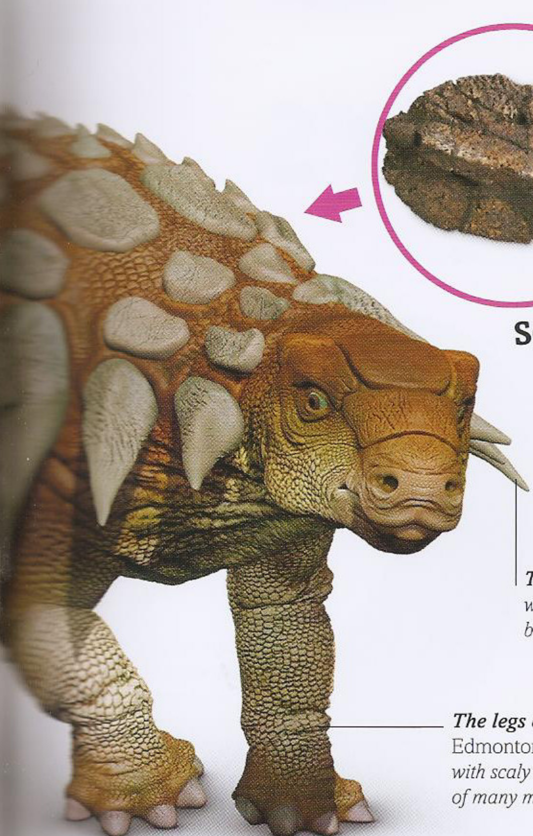

This armored dinosaur's scutes *were spike-shaped, partly for defense but perhaps also for show.*

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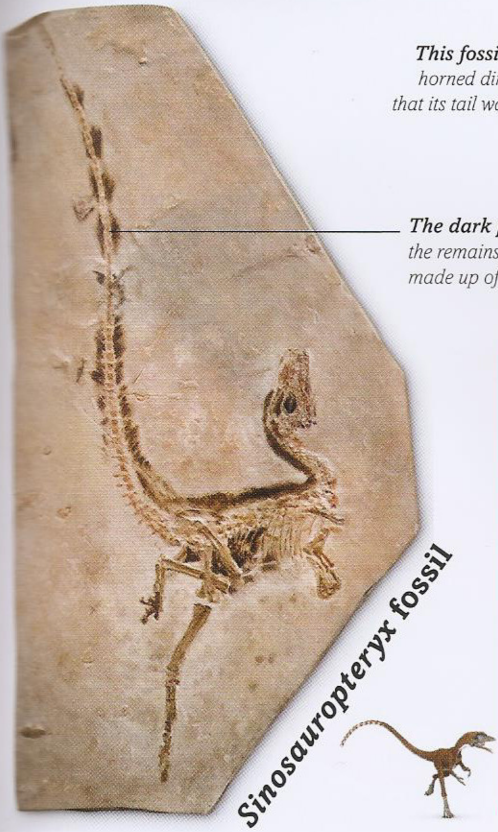

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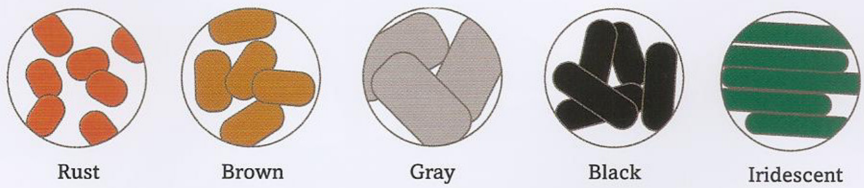
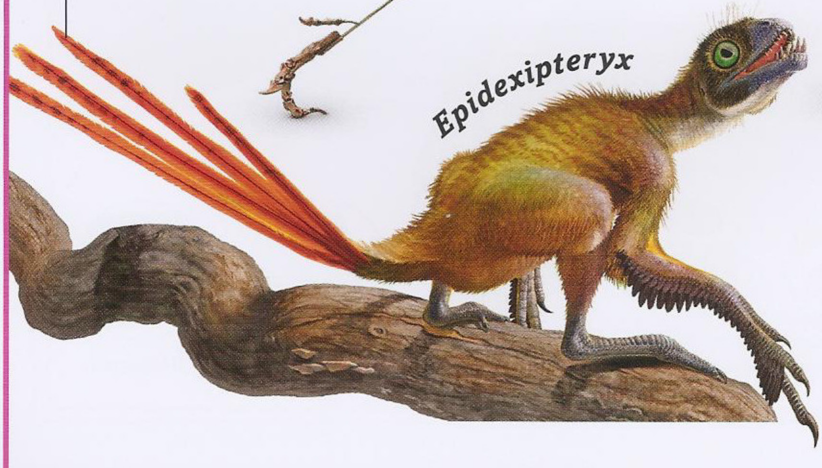


or protofeathers, resembling hair; these probably kept the animal warm, like the fur of a mammal. Others, including ***Caihong***, had fully vaned feathers, like those of modern birds. Some of these feathers were longer, especially on the arms, which would have looked like short wings. Microscopic analysis even indicates that some of the feathers were brightly colored. All this new evidence shows that there is little difference between these extinct theropod dinosaurs and living birds and supports the conclusion that birds are small, flying dinosaurs.

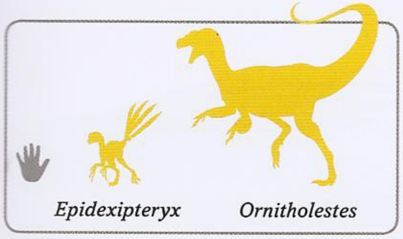
Feathered hunters

***Scipionyx* fossil**



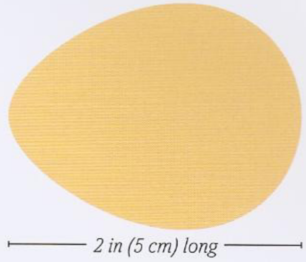
Like many small dinosaurs, ***Ornitholestes*** is known from just a **single** fossil.

For decades it has been clear that the skeletons of small, long-armed theropod dinosaurs like *Buitreraptor* are similar to that of the first known bird, *Archaeopteryx*. More recent fossil evidence also shows that the bodies of many of these lightweight hunters were covered with feathers of some kind. This means that the only difference between these small dinosaurs and the first birds was the length of their arms and the nature of their feathers. At first sight a small, agile hunter with fuzzy feathers such as ***Ornitholestes*** might not seem very like

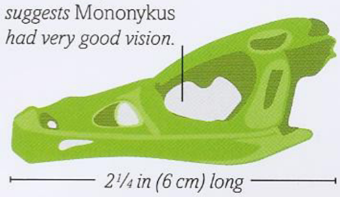


TINY SKULL

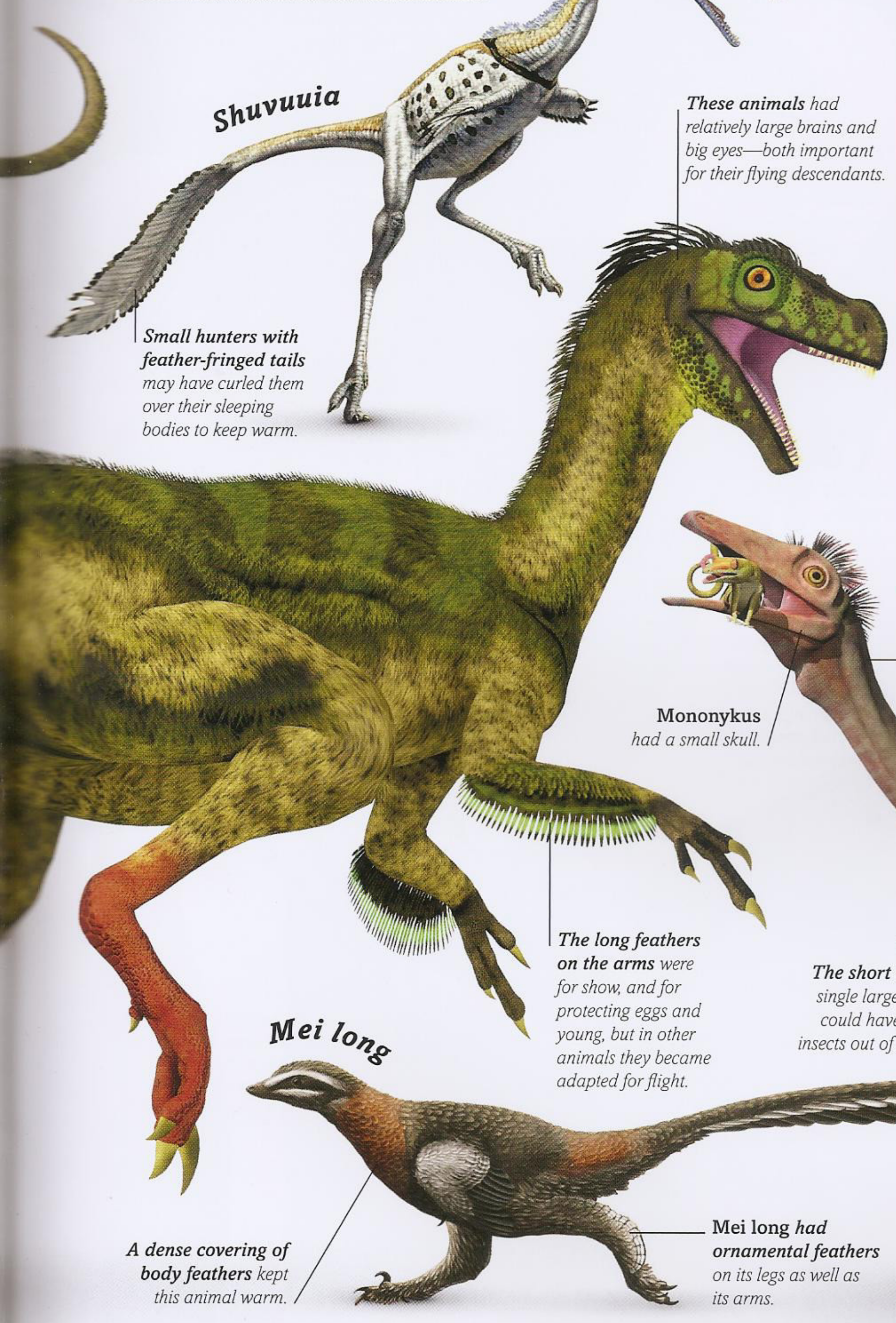
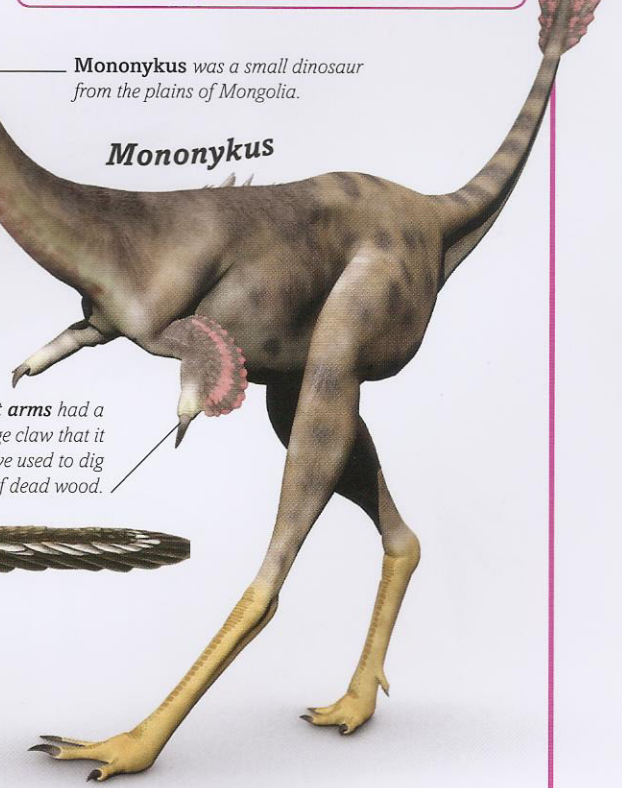
The skull of *Mononykus* was only slightly longer than a chicken egg. But its brain was quite large compared to its body size, suggesting that it was relatively intelligent. Its eyes were unusually big, indicating that they probably worked well in dim light, so it may have been most active at night or during the twilight of dawn and dusk.



Chicken egg



***Mononykus* skull**

a bird, but extend its arms and add some longer feathers, and it might look ready for take-off. The fossils of similar animals, like *Velociraptor*, show that they had long, birdlike feathers sprouting from their arms, and many also had feathery fans on their tails. A fossil of ***Epidexipteryx*** clearly shows four very long, ornamental tail feathers. This type of feathering made small hunters such as ***Mei long*** look like short-winged pheasants or chickens, and if they were alive today we would instantly recognize them as flightless birds.

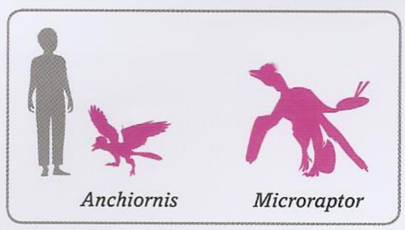
First up

The first birdlike dinosaurs evolved in the Jurassic Period at least 150 million years ago. They had toothed jaws and long, feather-fringed tails, just like many small nonflying hunters that lived at the time. They resemble birds because most of them had long, feathery wings that were clearly adapted for some sort of flight. But we do not know how well they could fly. The wing feathers of animals like ***Archaeopteryx*** and ***Jeholornis*** are similar to those of modern birds, but their shoulder joints did not allow them to raise their wings

Archaeopteryx was the first known **birdlike dinosaur**.

This well-preserved fossil clearly shows the birdlike feathers on its arms, legs, and tail.

Microraptor fossil

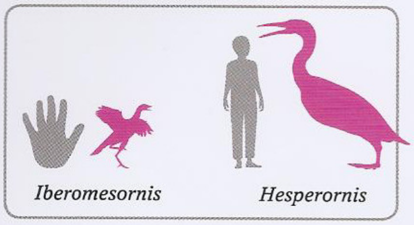


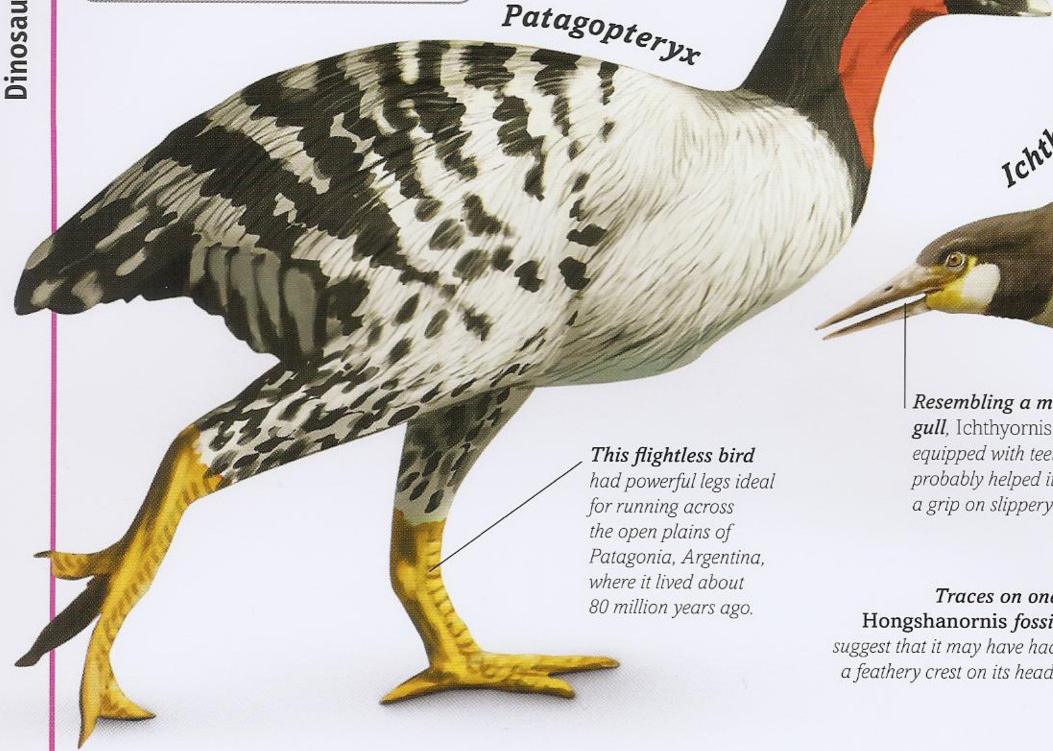
very high, and unlike modern birds, they did not have big breastbones to anchor powerful flight muscles. Some like ***Microraptor*** almost certainly could not fly in the true sense. It is possible that they were mainly adapted for gliding from tree to tree, but the feet of *Jeholornis* and many others were far better suited to life on the ground. So we still do not know exactly how these animals took to the air. We just know that they had long, broad wings, which would have been of little use if they could not fly in some way.

TAKING OFF In the late Jurassic Period, 150 million years ago, the age of dinosaurs still had more than 80 million years to run. But already, the first birdlike creatures were experimenting with flight. One of the earliest was *Archaeopteryx*, a crow-sized relative of agile hunters like *Velociraptor* that had particularly long arms with birdlike feathers. It was not exactly a bird, but it was close.

All the specimens of *Archaeopteryx* found so far lived in a region of Europe that was reduced to a group of dry islands surrounded by shallow seas. The islands seem to have had few trees, and *Archaeopteryx* probably ate small ground-living animals like lizards and insects. But its long, feathery wings must have been useful in some way. They may have helped it accelerate in pursuit of prey over the ground. It is also possible that, like modern chickens, it used them to fly up into tall shrubs to roost at night, out of reach of prowling hunters. It may have evolved in a region with taller trees and used its wings to glide between them. We do not know—but one day, another fossil may solve the riddle.

Early birds





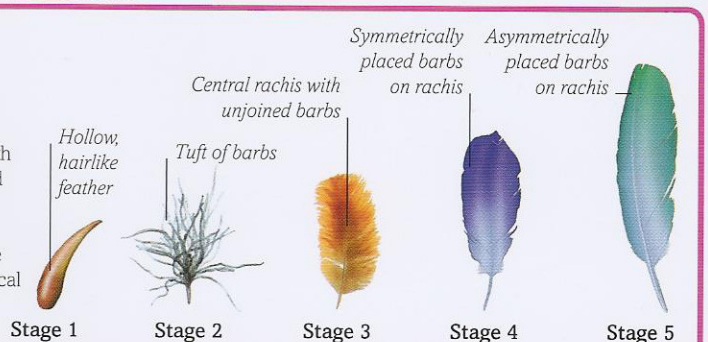
This flightless bird *had powerful legs ideal for running across the open plains of Patagonia, Argentina, where it lived about 80 million years ago.*

Resembling a modern gull, Ichthyornis *was equipped with teeth that probably helped it keep a grip on slippery fish.*

Traces on one **Hongshanornis** ***fossil*** *suggest that it may have had a feathery crest on its head.*

EVOLUTION OF FEATHERS

Between the early Jurassic and the Cretaceous, feathers evolved from hollow filaments to the form seen in modern birds. Over time, they developed a main shaft, or rachis, with increasingly complex branches called barbs that zipped together to form vanes. Early vaned feathers had a central rachis, but in later feathers the rachis is off-center. These asymmetrical feathers made more efficient wings and were the key to effective flight.



In the Cretaceous Period, about 25 million years after *Archaeopteryx* made its first clumsy flight, the early birdlike dinosaurs started giving way to more modern-looking birds like *Confuciusornis*. This is one of the oldest short-tailed, toothless birds known, although it still had substantial wing claws. Like other birds of the same period, including the sparrow-sized ***Iberomesornis*** and the slightly bigger ***Concornis***, it had a big breastbone for anchoring flight muscles; it must have been able to fly well. In time, birds like ***Hongshanornis***

To aid flight, *the wing feathers were asymmetrical, like those of modern birds.*

Concornis was about the same size *as a starling, but not as agile in the air.*

***A male* Confuciusornis** *had two long tail streamers.*

Hesperornis *was about 6 ft (1.8 m) long.*

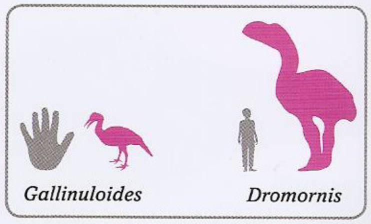
The wings *of this enormous toothed seabird were reduced to tiny stumps, so it could not fly.*

Strong claws and a back-pointing toe *on each foot allowed* Iberomesornis *to perch on branches.*

Hesperornis *swam using its large webbed feet.*

became more specialized for flight, with stronger skeletons to resist flight stresses. Many still had small teeth, especially fish-eating seabirds like ***Ichthyornis***, which lived about 90 million years ago. But others had abandoned them in favor of beaks, and by the late Cretaceous, about 70 million years ago, many modern-type birds were flying over the heads of the giant dinosaurs. Some birds, including ***Patagopteryx***, had given up flight to live like ostriches, while the flightless ***Hesperornis*** hunted underwater like a giant cormorant.

Giant birds



At 10 ft (3 m) tall, *Dromornis* was the **largest bird** that ever existed.

Dromornis

The massive legs *of* Dromornis *supported its colossal weight—it weighed 10 times as much as a human.*

Terror birds *had huge, hooked beaks for killing and tearing the flesh of their victims.*

Phorusrhacos

Phorusrhacos *had a very flexible neck that allowed it to strike quickly at prey.*

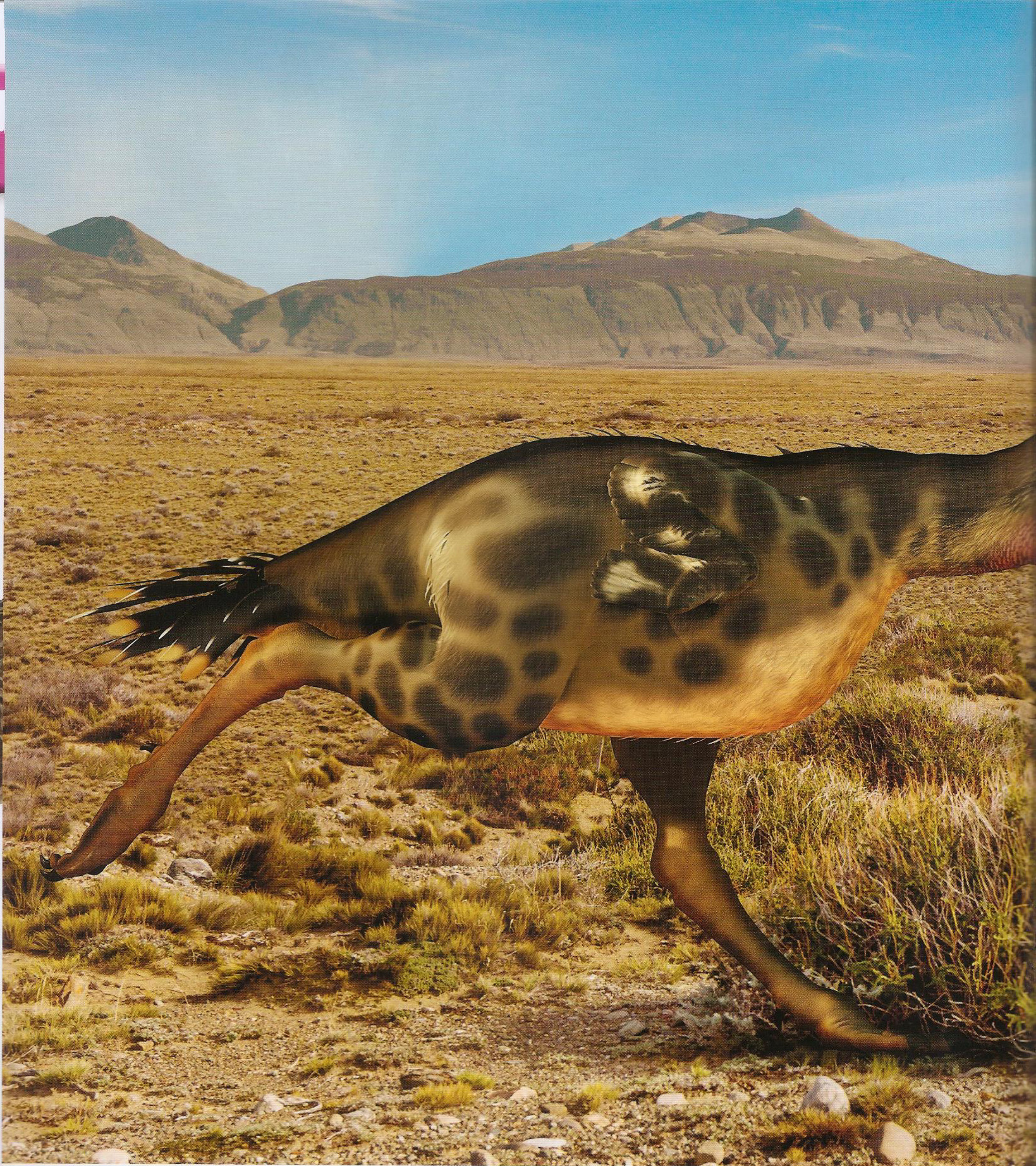
Sharp claws *were used to pin struggling prey to the ground as the bird prepared to kill and eat it.*

This fossil *shows that birds very similar to modern chickens were living in North America 48 million years ago.*

Gallinuloides fossil

Birds were the only dinosaurs to survive the mass extinction that wiped out their giant relatives 66 million years ago. They evolved to form many new types that are still with us today, including owls, ducks, and penguins. By about 40 million years ago, most of the familiar bird groups had appeared, but there were also a few very unfamiliar birds, including giant, flightless predators known as "terror birds." They included ***Phorusrhacos*** and ***Titanis***. Both were more than 8 ft (2 m) tall and had hooked beaks and huge claws for

ripping apart prey on the open plains of North and South America. They were among the most powerful predators of their time. Another flightless giant, the Australian ***Dromornis***, probably ate plants, and the same may apply to the much earlier ***Gastornis***. Meanwhile, some airborne birds were also giants. ***Argentavis***, which soared above the plains of Argentina more than 5 million years ago, was a colossal, vulturelike bird of prey with an 26 ft (8 m) wingspan, and probably the largest flying bird that has ever lived.

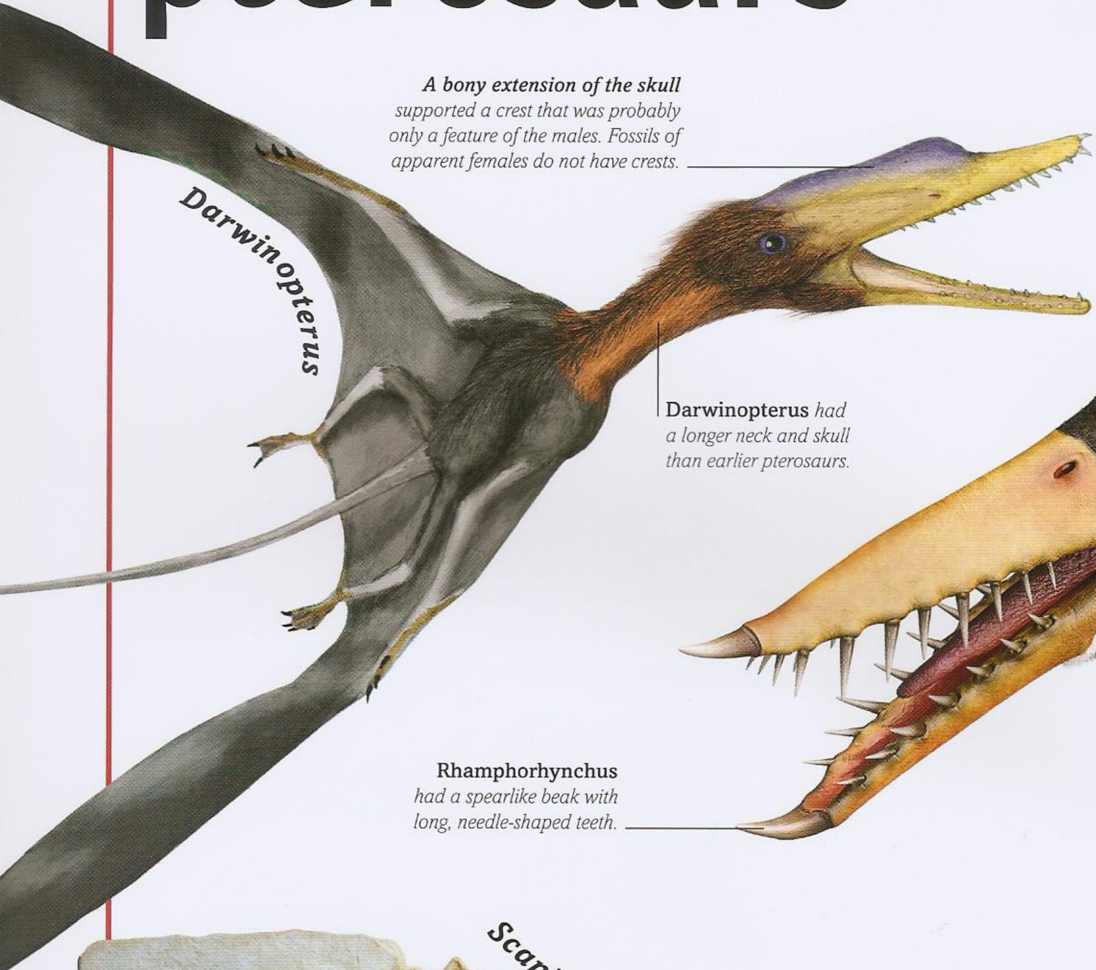


HIGH-SPEED KILLER With its long legs and massive hooked beak, *Kelenken* was one of the fastest, most powerful predators of its era. The biggest of the ferocious "terror birds," it hunted in the open plains of Patagonia, South America, about 15 million years ago. Its main prey were probably small mammals, but it may have had the speed and strength to hunt bigger victims.

Discovered in 2006, the virtually intact fossil skull of *Kelenken* was 28 in (71 cm) long, making it the biggest bird skull ever found. Its enormous, immensely strong hooked beak would have been like that of a gigantic eagle, and *Kelenken* probably used it in the same way to rip larger prey to pieces; it would have swallowed small animals whole. About 10 ft (3 m) tall, *Kelenken* had long, muscular legs that ensured it could outrun most of its victims, and it probably caught and even killed them by seizing and gripping them with its claws. It was so powerful that it may have driven other hunters off the open plains and into the forests, where its height would have made it a less effective predator.

PTEROSAURS

Early pterosaurs



A bony extension of the skull supported a crest that was probably only a feature of the males. Fossils of apparent females do not have crests.

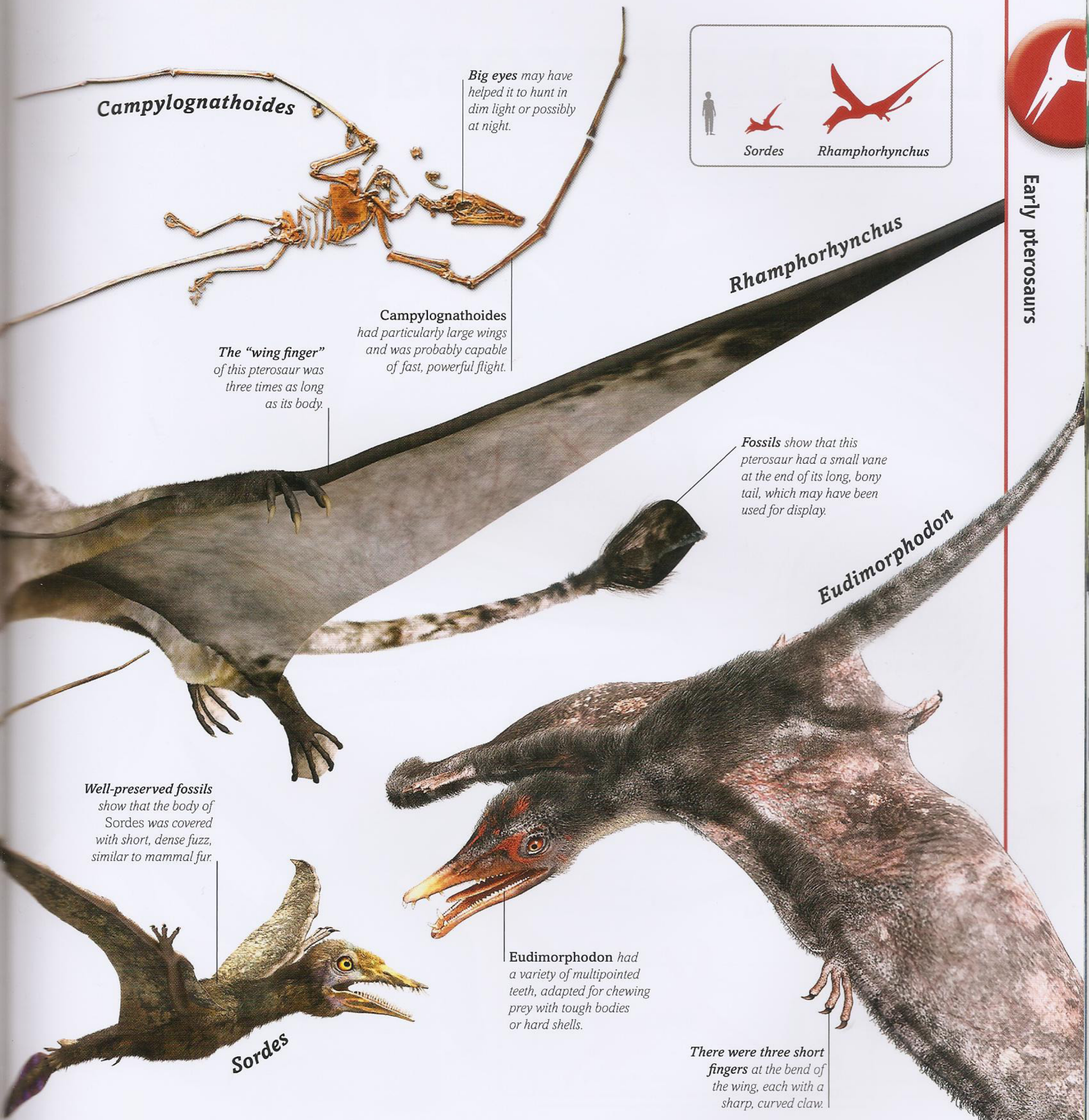
Darwinopterus *had a longer neck and skull than earlier pterosaurs.*

Rhamphorhynchus *had a spearlike beak with long, needle-shaped teeth.*

***A long, bony tail** was a distinctive feature of all early type pterosaurs; later ones had much shorter tails.*

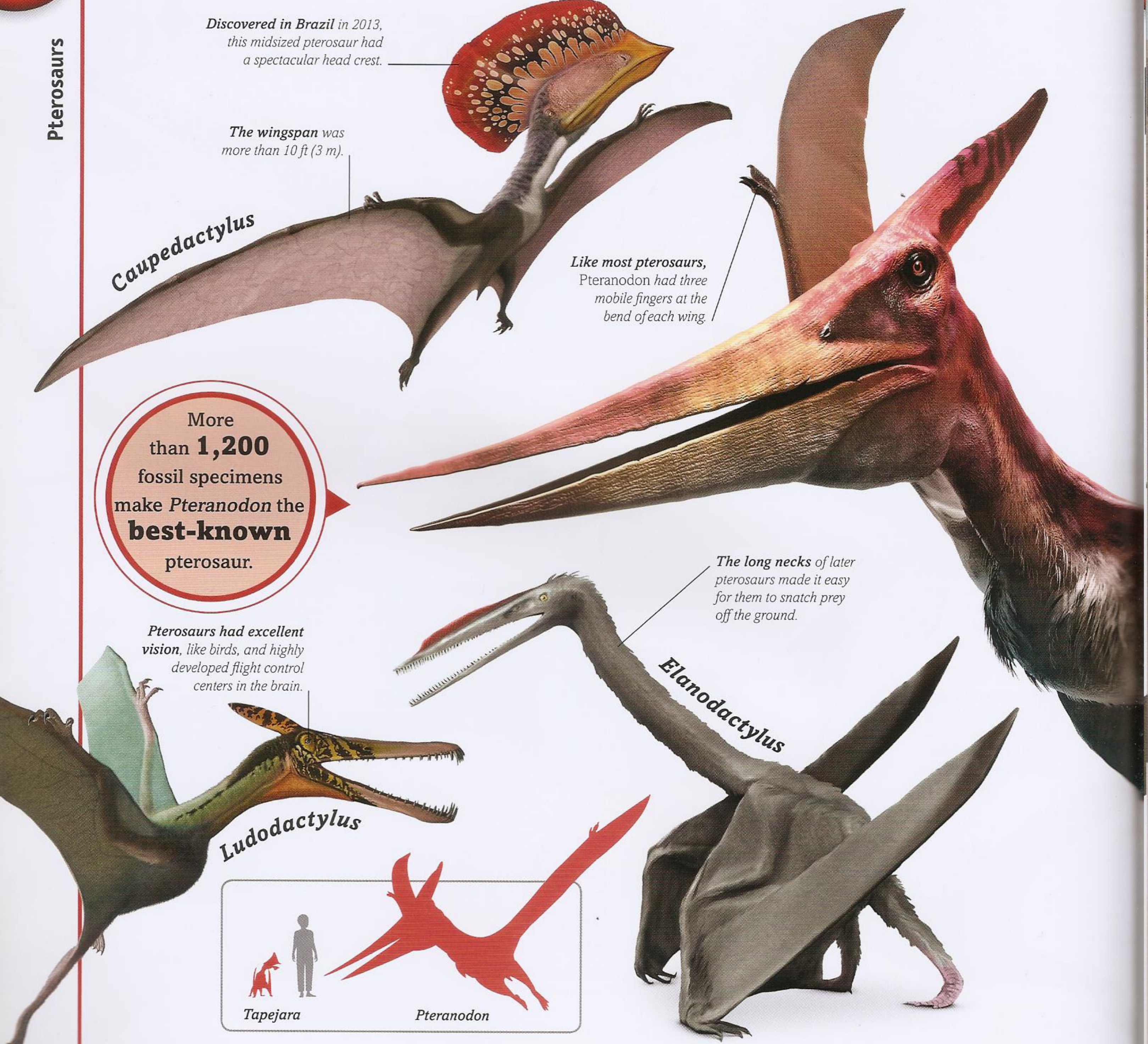
***The long fourth finger bone** was sturdy to support the entire length of the outer wing.*

The giant dinosaurs shared their world with close relatives called pterosaurs—flying reptiles that flew on wings of stretched skin. Their wings were similar to those of bats, but supported by the bones of just one hugely elongated finger. They were strengthened with springy fibers and contained sheets of muscle that continually adjusted the wing's shape to make it work as efficiently as possible. Pterosaurs had small, furry, and light bodies; excellent eyesight; and relatively big brains. The earliest ones found so far—



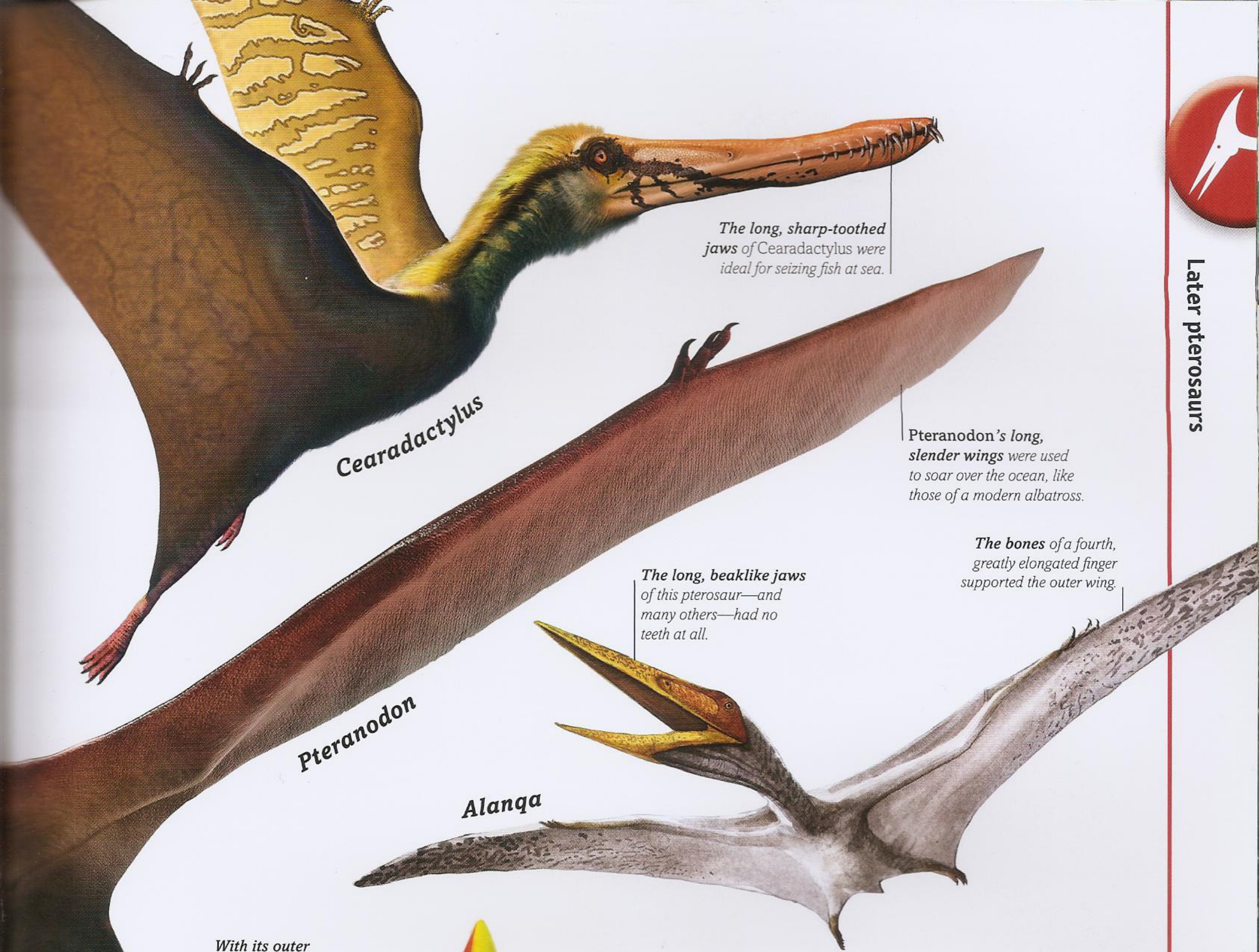
crow-sized animals like ***Eudimorphodon***—appeared in the late Triassic Period, more than 210 million years ago. They had short necks, long, bony tails, and most had jaws armed with a variety of sharp teeth to suit their diet. Some, such as ***Rhamphorhynchus***, caught fish, possibly by swooping down from the air. Others, like ***Sordes*** and ***Dimorphodon***, probably fed mainly on insects and other small animals that they caught on the ground or while climbing trees using their sharp wing claws.

Later pterosaurs



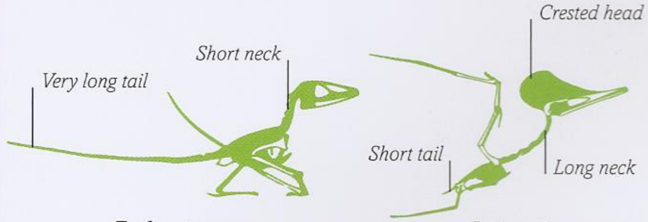
More than **1,200** fossil specimens make *Pteranodon* the **best-known** pterosaur.

During the Jurassic Period, about 166 million years ago, pterosaurs with a new body plan started appearing. They had longer necks, shorter tails, and were also better adapted to life on the ground—evidence from fossil footprints shows that many of them, including ***Tapejara*** and ***Elanodactylus***, regularly walked on all fours, with their outer wings folded out of the way. Some pterosaurs were probably agile enough to hunt like this. Others, like ***Pteranodon*** and ***Cearadactylus***, seem to have hunted at sea—they were probably



HOW PTEROSAURS EVOLVED

Early pterosaurs were typically crow-sized animals with long, bony tails, short necks, and powerful jaws bristling with pointed teeth. During the Jurassic Period, they gradually gave way to bigger, short-tailed pterosaurs with longer necks and long, often toothless jaws. Many of these later pterosaurs also had spectacular crests on their heads.



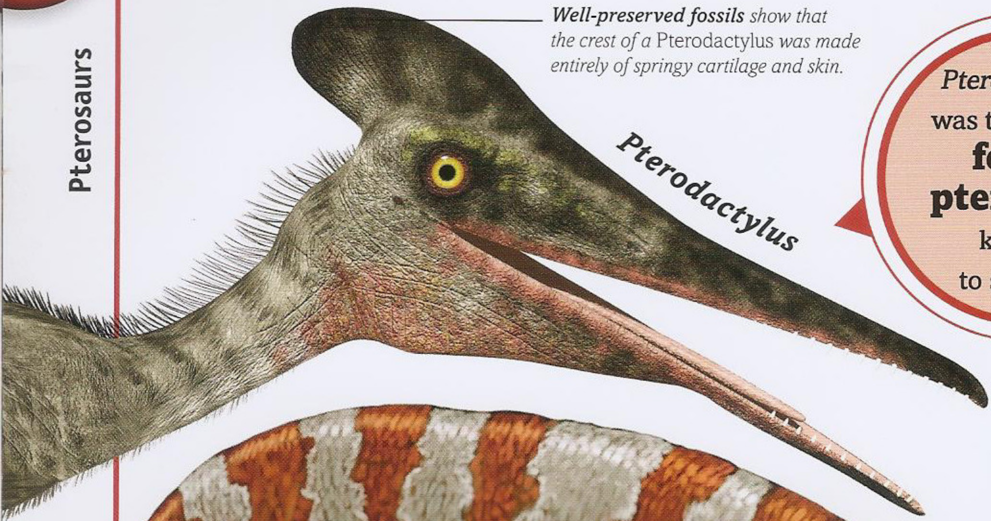
able to swim on the ocean surface like seabirds and dive briefly below to catch fish. Many of these later pterosaurs were giants compared to the earlier ones. *Pteranodon* had a wingspan of more than 23 ft (7 m), and the biggest of all—*Quetzalcoatlus* and *Hatzegopteryx*—were the size of small aircraft, with wingspans of 33 ft (10 m) or more. These were the largest flying animals that ever lived, and all the evidence suggests that they were excellent fliers, able to cover vast distances by soaring on rising air currents like gigantic vultures.

PROWLING PREDATOR

The smaller dinosaurs that lived in North America 70 million years ago often fell prey to tyrannosaurs, but they also faced danger from another direction—the air. High above them, the skies were patrolled by *Quetzalcoatlus*, a gigantic pterosaur that would have soared in circles on rising air currents like a huge bird of prey, watching for a chance to seize a meal.

Quetzalcoatlus was superbly adapted for flight and had excellent eyesight for targeting prey from long range. But it did not have powerful claws for seizing prey from the air. So it probably landed first, folded up its long outer wings, and stalked on all fours through the undergrowth in search of food. As tall as a giraffe, *Quetzalcoatlus* could stand with its head well clear of any bushes or small trees. Its long neck and jaws also gave it a very long reach, so it could ambush animals from cover before they knew they were being watched. Since *Quetzalcoatlus* lacked teeth or a hooked beak, it could not tear prey apart, but it was big enough to swallow dinosaurs like this baby titanosaur whole.

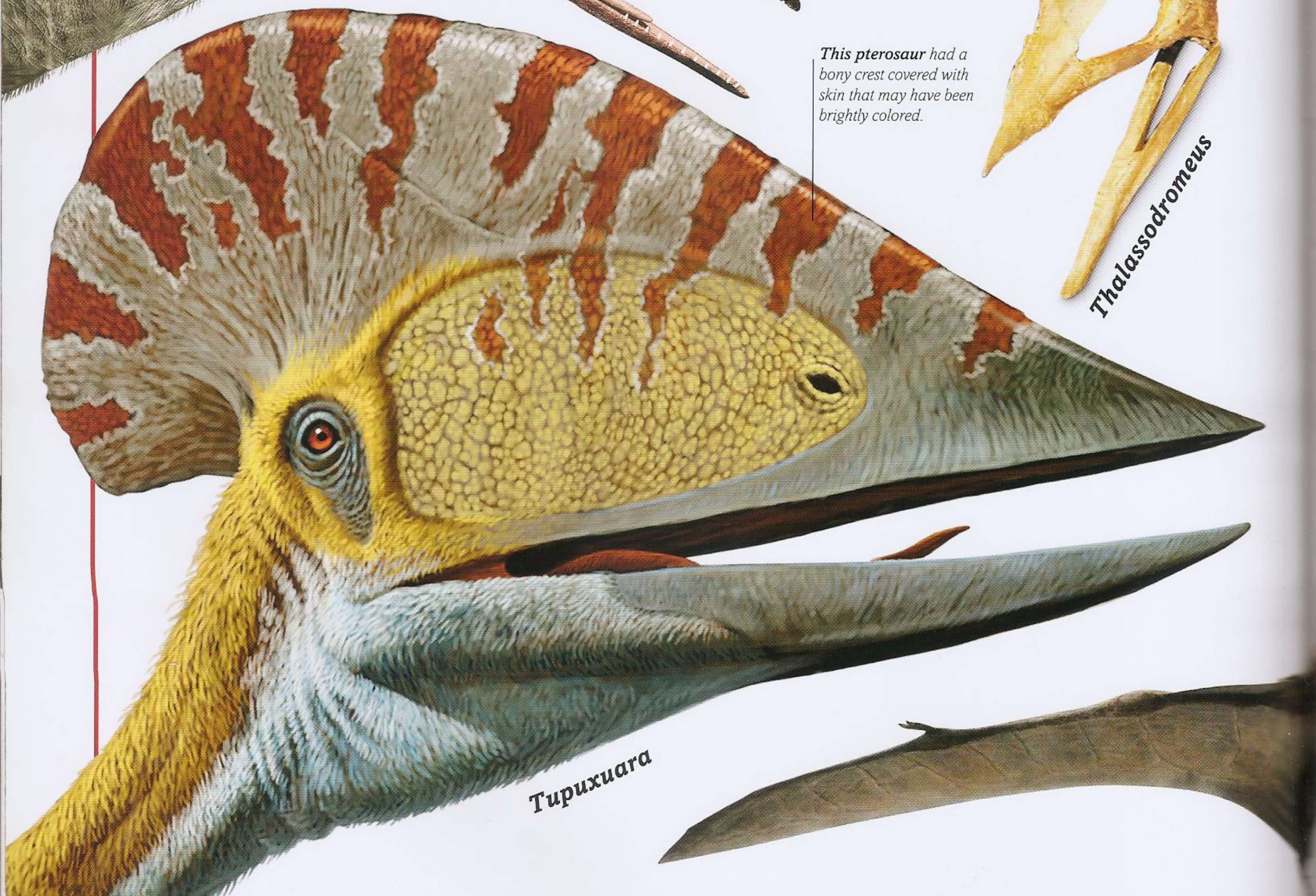
Colorful crests



Well-preserved fossils *show that the crest of a* Pterodactylus *was made entirely of springy cartilage and skin.*

Pterodactylus was the **first fossil pterosaur** known to science.

***The crest of* Thalassodromeus** *contained a thin sheet of bone.*

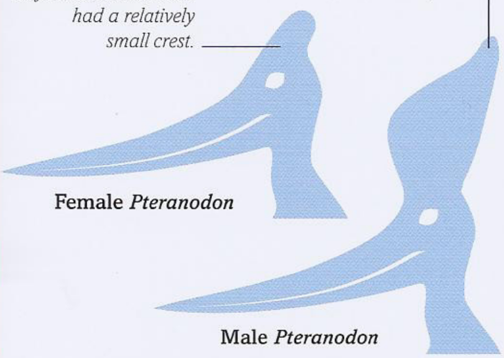


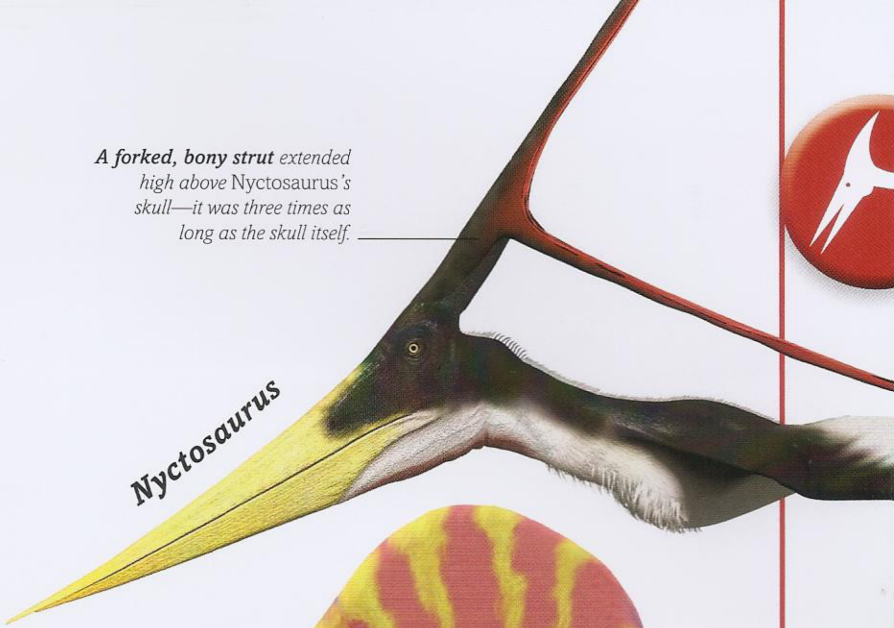
This pterosaur *had a bony crest covered with skin that may have been brightly colored.*

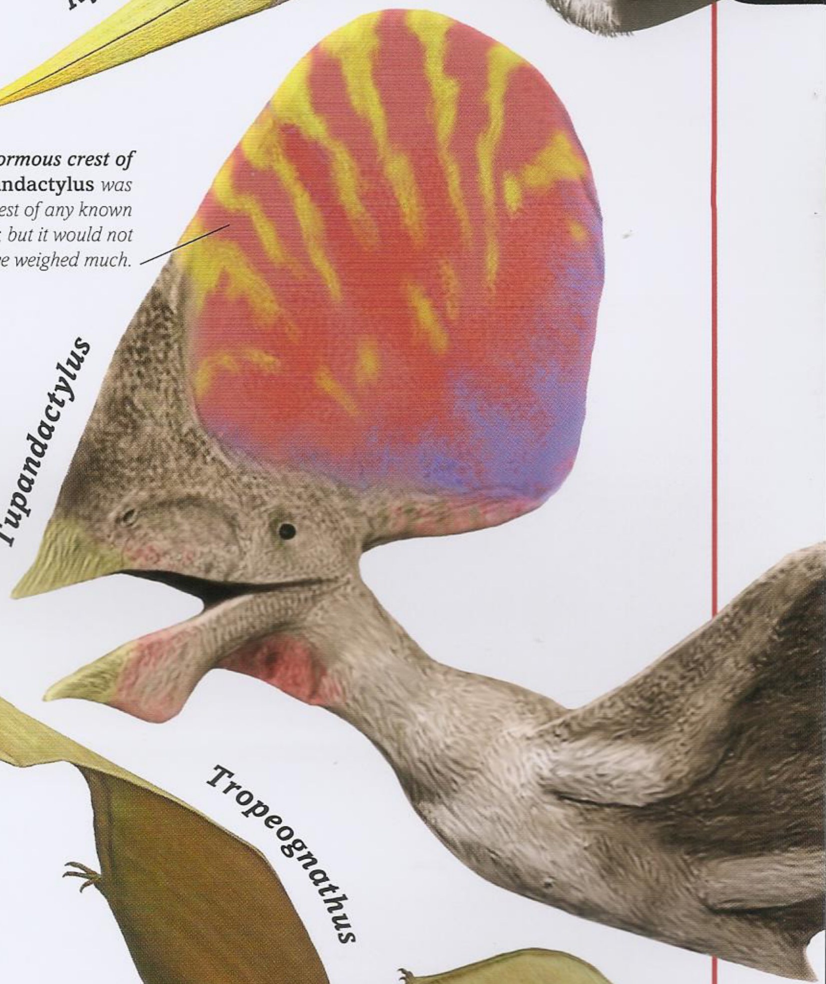
The heads of many later pterosaurs had spectacular crests that were almost certainly for display to rivals and potential breeding partners. The crests of ***Tupandactylus*** and ***Nyctosaurus*** were huge but lightweight structures made of skin or horn supported by slender, bony struts. The smaller crest of ***Thalassodromeus*** was based on a thin, lightweight plate of bone, while the crests of other species, including ***Pterodactylus***, were made entirely of soft tissue. Pterosaur

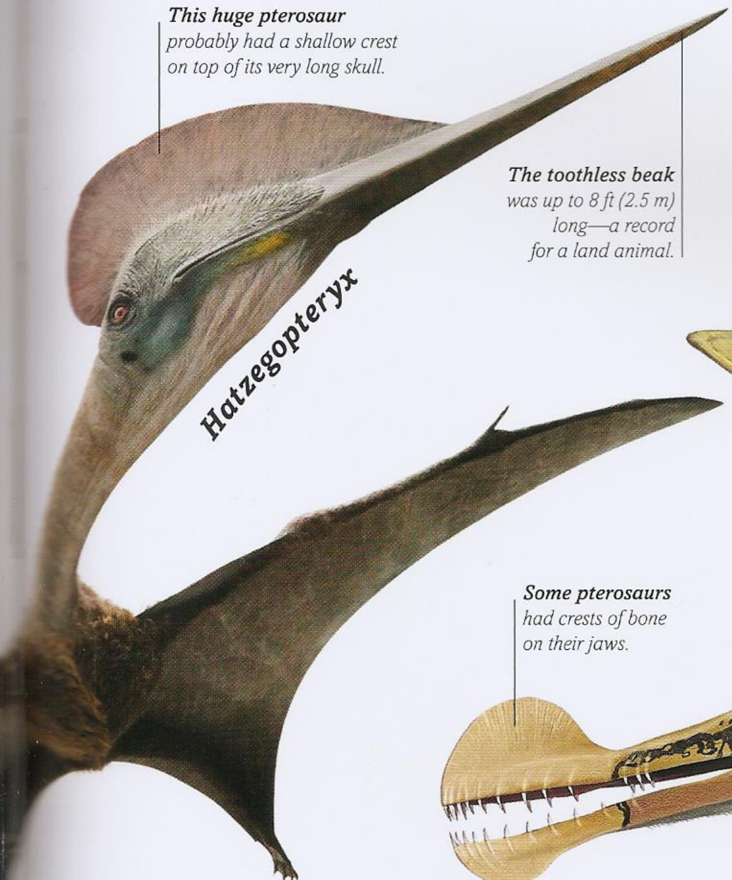
POMP AND SHOW

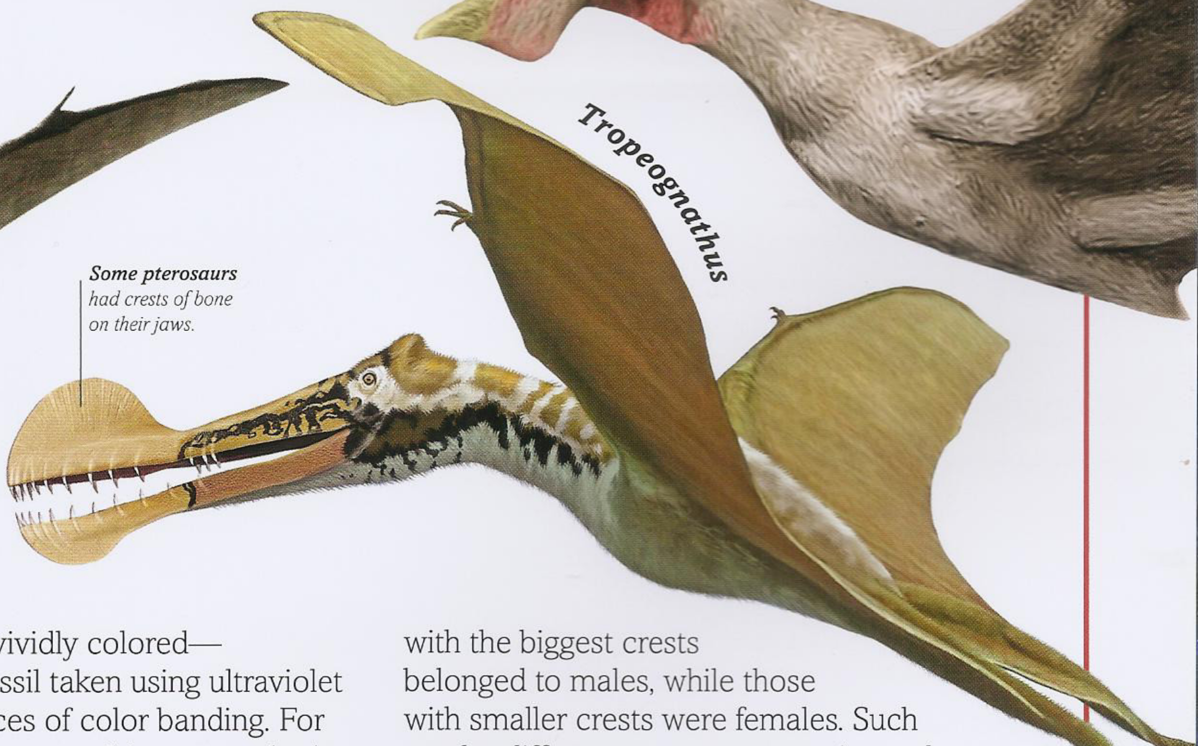
Many complete skeletons of *Pteranodon* have been found, and by examining the pelvic bones, scientists can distinguish between males and females. The males have larger crests, which shows they were important in courtship, like the decorative feathers of birds such as peacocks.











crests were probably vividly colored—photographs of one fossil taken using ultraviolet light show distinct traces of color banding. For most pterosaurs, it is not possible to say whether males and females both had crests, but in the case of *Pteranodon*, it is clear that fossil skulls with the biggest crests belonged to males, while those with smaller crests were females. Such gender differences are common in modern birds. Male peacocks, for instance, have longer tails and brighter colors than females.

THE MARINE WORLD

Life in Mesozoic seas

This giant fish had *meshlike plates at the back of its mouth for sifting tiny drifting animals from the water.*

Leedsichthys

Ammonite

The coiled shell *protected the ammonite's soft body.*

Crab fossil

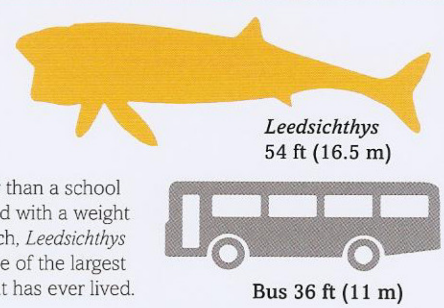
The shell *was more than 2 in (5 cm) across.*

This crab *lived in warm, shallow seas about 80 million years ago.*

Sea snail fossil

This fossil *shows the protective spiral shell made of hard, chalky minerals absorbed from seawater.*

LARGEST FISH



Longer than a school bus, and with a weight to match, *Leedsichthys* was one of the largest fish that has ever lived.

The Paleozoic Era—the age of ancient life—ended 251 million years ago with a devastating mass extinction of life. This event was so extreme that it destroyed about 96 percent of all marine species. During the centuries that followed—the earliest years of the Mesozoic age of dinosaurs—the oceans would have been almost lifeless. But some animals survived and started to multiply, taking advantage of all the empty space. It took about 5 million years for the real recovery to begin, as the surviving marine animals evolved into

A seabed dweller, *this crinoid used its petal-like arms to filter food from seawater.*

The long stem *at the base of its body was attached to a hard surface.*

Crinoid fossil

The streamlined body *of this squidlike mollusk probably made it a fast swimmer.*

Like a squid, *the belemnite caught prey with two long, suckered tentacles.*

Belemnite

Although very similar to modern horseshoe crabs, *this one lived at the same time as the giant dinosaurs.*

Horseshoe crab fossil

After 150 million years, **shiny scales** are still visible on this amazing fossil.

Brittlestars *are slender, flexible starfish that have been foraging for food on the seabed for 500 million years.*

Brittlestar fossil

Fossils *of the 6-ft- (1.8-m-) long* Lepidotes *have been found throughout the world.*

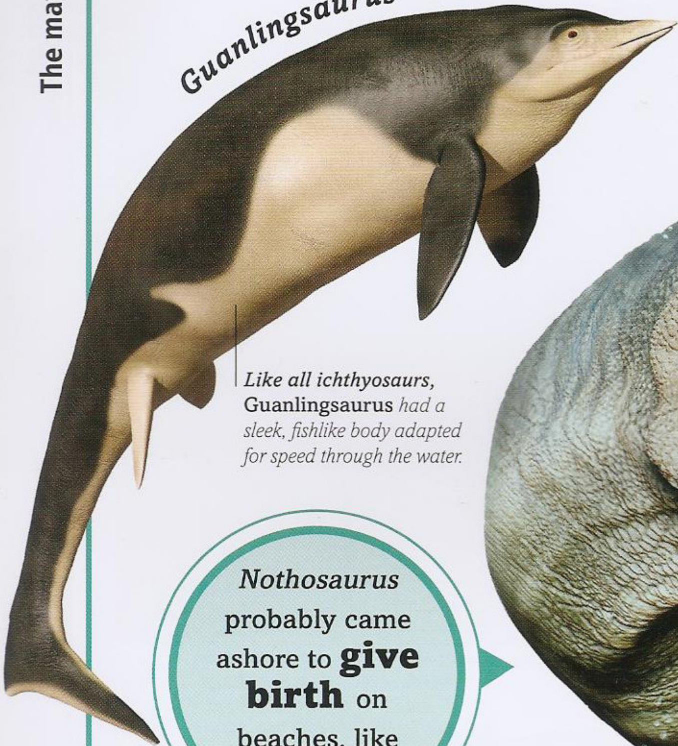
The blunt, teardrop-shaped teeth *were used to break open shellfish.*

***Lepidotes* fossil**

many new forms. These included **fish**, sharks, and marine reptiles, as well as invertebrates such as shelled mollusks, **crabs**, and **starfish**. Hard-shelled invertebrates in particular were common and have been fossilized in large numbers. They included **ammonites** and **belemnites**, both of which were relatives of squid. They perished in the mass extinction that ended the Mesozoic Era and destroyed the giant dinosaurs. But other types of sea creature survived and still flourish in the world's oceans.

Early marine reptiles

Unusually, this broad-mouthed reptile *seems to have been a herbivore that fed on seaweed, like a modern marine iguana.*



Like all ichthyosaurs, **Guanlingsaurus** *had a sleek, fishlike body adapted for speed through the water.*

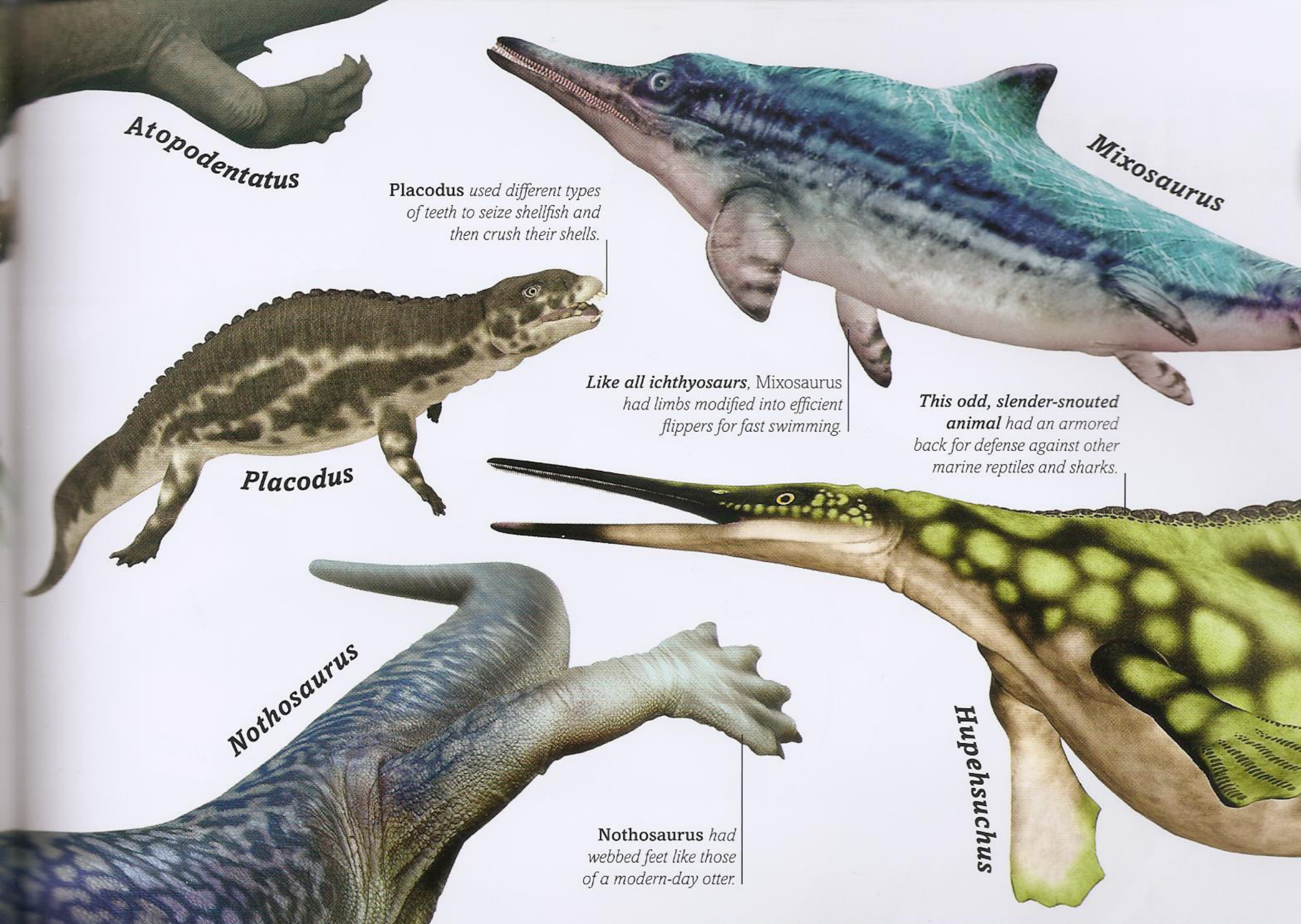
The head was long and flat *with very powerful jaws, like the head of a modern crocodile.*

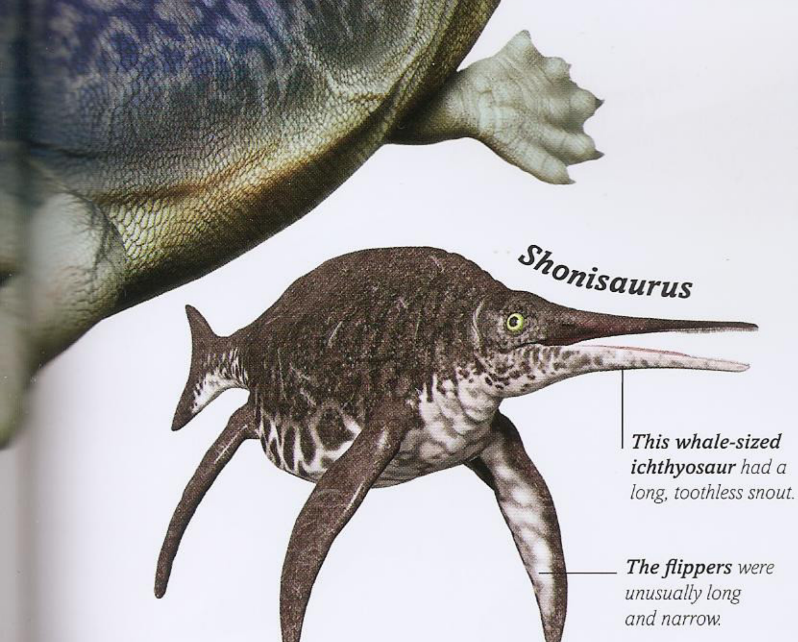
The long teeth *interlocked to trap fish and other slippery prey.*

Nothosaurus probably came ashore to **give birth** on beaches, like a **seal**.

Henodus *had a protective shell made of plates of bone.*

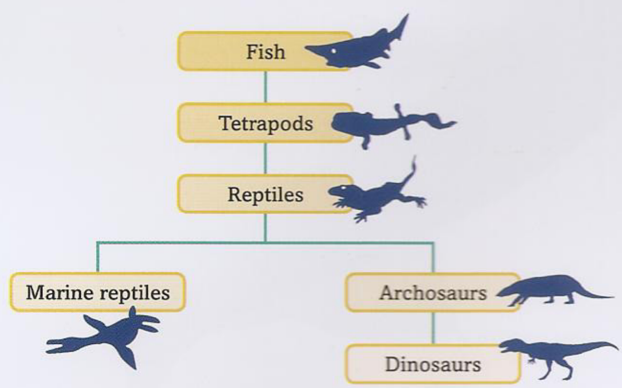
The fish and other sea animals that lived during the time of the dinosaurs were preyed on by reptiles that were specially adapted for life in the oceans. These reptiles started becoming common in the ocean about 245 million years ago, in the Triassic Period, and rapidly evolved a variety of adaptations for eating different kinds of food. Four-legged placodonts like ***Placodus*** searched the seabed for hard-shelled clams and similar shellfish, and other reptiles including ***Atopodentatus*** grazed on seaweed.





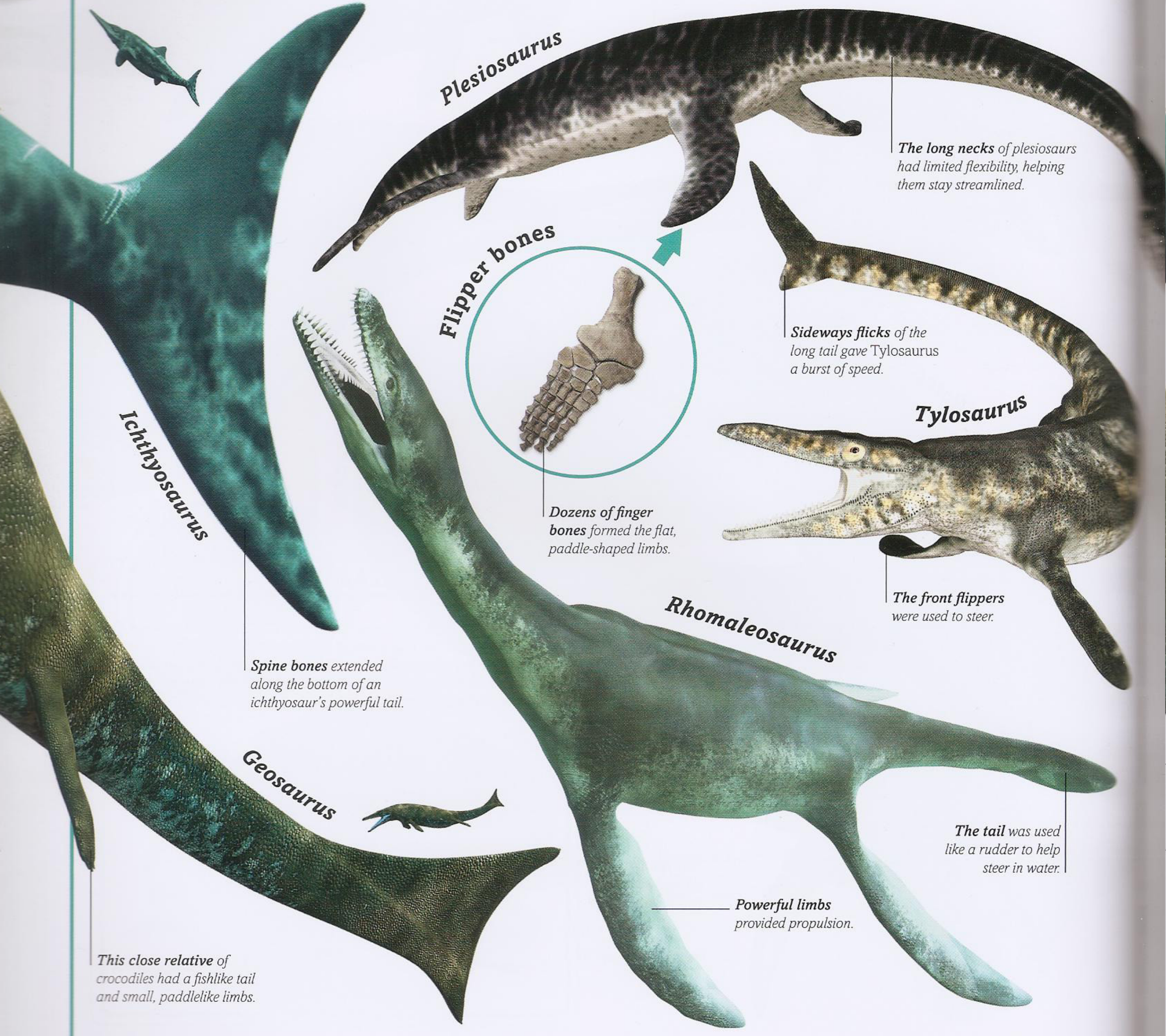
OCEANIC LIZARDS

Marine reptiles were the oceanic counterparts of the giant dinosaurs that lived on land, but only a few of them were archosaurs—the group of reptiles that included dinosaurs. Most marine reptiles belonged to a different branch of the reptile family tree and were more closely related to lizards and snakes than dinosaurs.



Equipped with sharp-pointed teeth, the crocodilelike **Nothosaurus** preyed on other marine animals, as well as fish. Most of these early marine reptiles had legs and probably lived partly on the shore, like seals. But the dolphinlike ichthyosaurs—animals like ***Mixosaurus*** and ***Shonisaurus***—were fully adapted to live permanently at sea, even though they had to breathe air. Their streamlined bodies and powerful tails were similar to those of sharks, enabling them to swim very fast in pursuit of fish.

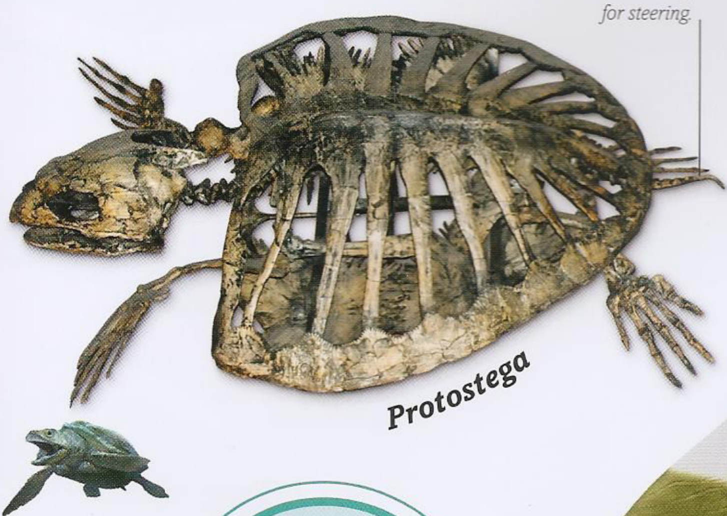
Flippers and tails



Many kinds of prehistoric reptiles gave up life on land to live in the ocean. Just as marine mammals like seals and whales would do later, they adapted to life in water by becoming streamlined and slippery and using their limbs as flippers. ***Nothosaurus*** had paddlelike, webbed feet for swimming, but it could also haul itself onto land to breed, as seals do. Other marine reptiles were fully aquatic and probably more agile in the water. ***Plesiosaurus*** and its shorter-necked relative ***Rhomaleosaurus*** propelled themselves through water by rowing

The webbed feet *would have been useful on land as well as for swimming.*

Ichthyosaurs *beat their tail flukes sideways, as sharks do.*



The hind flippers *of turtles are used only for steering.*

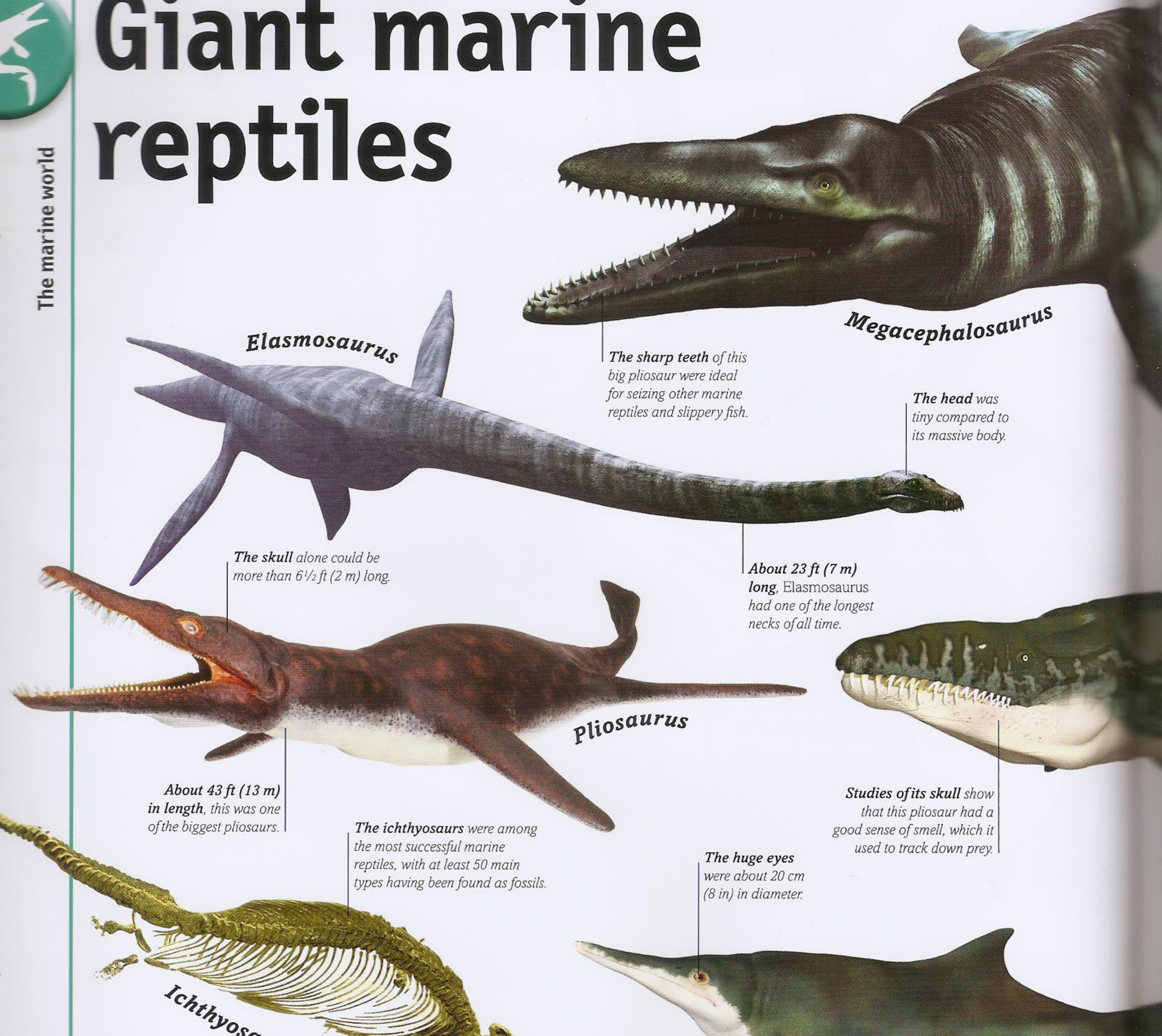
Tail muscles gave **mosasaurs** the power needed for **ambush** attacks.

Some mosasaurs *had crescent-shaped tail flukes.*

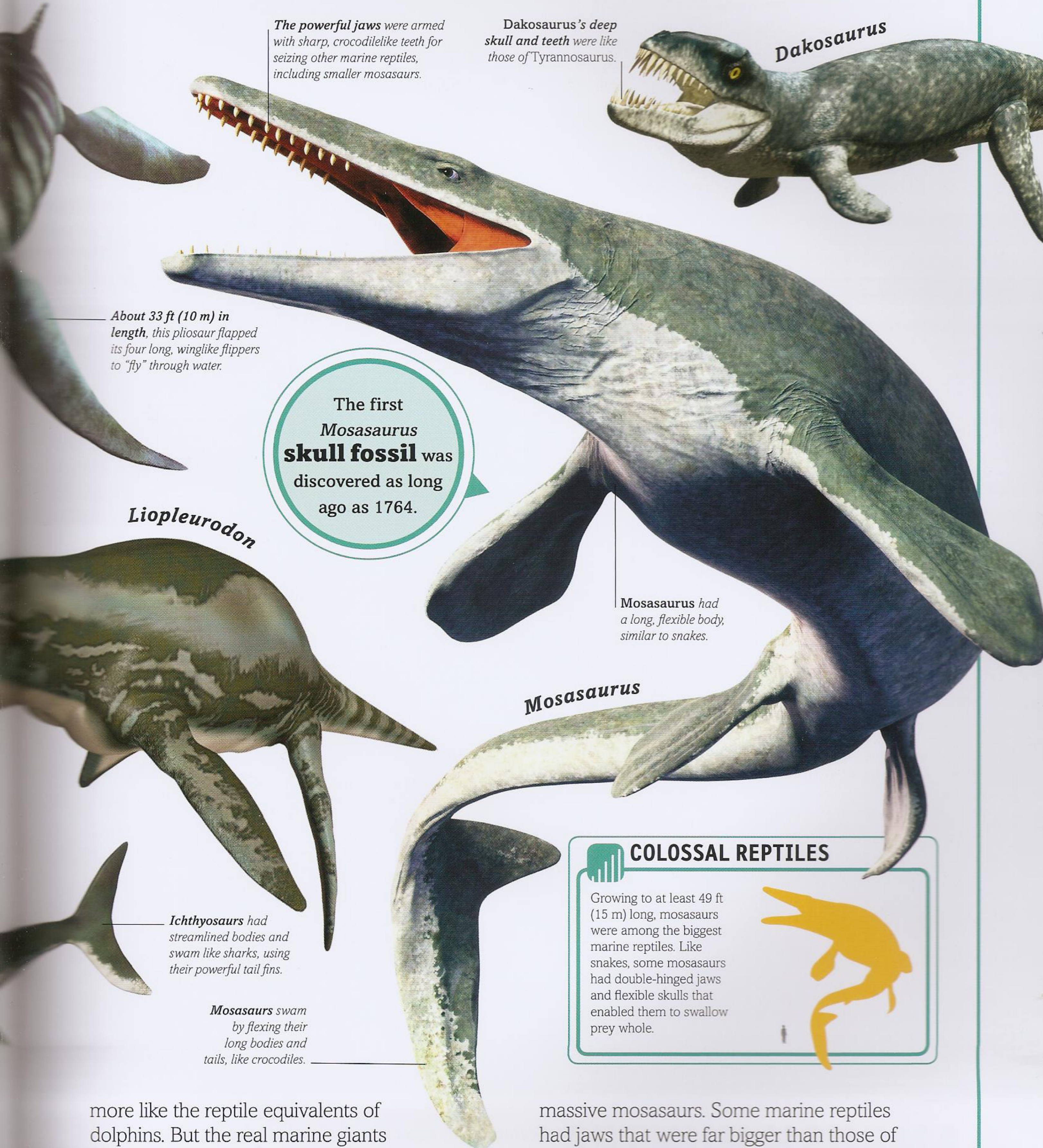
Front flippers *were used to steer.*

or flapping their winglike flippers. Whether they used all four for propulsion or just the front ones for propulsion and rear pair for steering (like turtles) is unclear. The fastest swimmers of the reptile world were ichthyosaurs, such as ***Ichthyosaurus*** and ***Stenopterygius***. They beat their sharklike tail flukes sideways for thrust and steered with their flippers. Early mosasaurs had flattened, crocodilelike tails that they swept from side to side to drive themselves through water. Later ones like ***Mosasaurus*** evolved tail flukes for greater efficiency.

Giant marine reptiles



Reptiles flourished in the oceans during the Triassic Period. But about 200 million years ago, the Triassic Period came to an end with a mass extinction that destroyed many of the spectacular reptiles that had ruled the seas. The survivors took a long time to recover, but over the next 135 million years they evolved into some of the most powerful predators that have ever existed. Some, like ***Dakosaurus***, resembled crocodiles but were specialized for life at sea. ***Ichthyosaurus*** and its giant relative ***Temnodontosaurus*** were



COLOSSAL REPTILES

Growing to at least 49 ft (15 m) long, mosasaurs were among the biggest marine reptiles. Like snakes, some mosasaurs had double-hinged jaws and flexible skulls that enabled them to swallow prey whole.

more like the reptile equivalents of dolphins. But the real marine giants were the long-necked reptiles known as plesiosaurs, which included ***Elasmosaurus***, as well as the short-necked, fearsome pliosaurs like ***Liopleurodon***, and the massive mosasaurs. Some marine reptiles had jaws that were far bigger than those of the deadly dinosaur *Tyrannosaurus*. All these marine reptiles were wiped out 66 million years ago in the mass extinction that killed the giant dinosaurs.

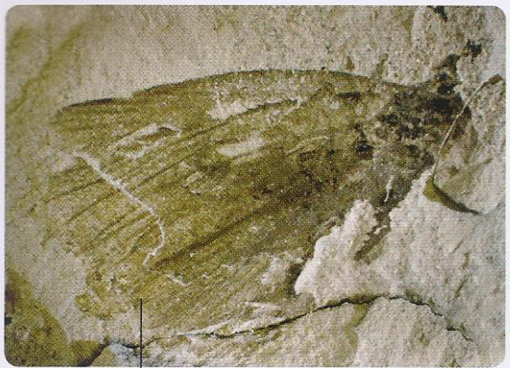
AMBUSH HUNTER

Some of the most deadly hunters that have ever existed lurked in the oceans during the Mesozoic Era. They included the pliosaurs—massive-jawed animals that were specialized for hunting big, powerful prey, including other marine reptiles. *Liopleurodon* was typical of these oceanic predators. About 23 ft (7 m) long and armed with huge, spike-shaped teeth, it had no predators.

Liopleurodon lived in the late Jurassic oceans more than 163 million years ago. It was related to the long-necked plesiosaurs like the ones seen here, but that did not stop it from hunting them. Both these species drove themselves through the water with their long flippers. Experiments using swimming robots have shown that this could have given them tremendous acceleration. *Liopleurodon* may have used this speed as a part of its hunting strategy—lying in wait in the gloomy depths before surging to seize its prey and ripping it apart, although it could probably swallow this plesiosaur whole. A successful, formidable predator, *Liopleurodon* existed for nearly 10 million years.

THE RISE OF MAMMALS

A new world



Butterfly fossil

This nectar-feeding butterfly *was found fossilized in rocks more than 50 million years old.*

Dawn redwood leaves

The dawn redwood *is almost identical to conifers that lived 150 million years ago, which provided food for giant dinosaurs.*

Seeds *are contained in scaly cones.*

Magnolia

Still thriving today, *magnolia flowers first blossomed more than 130 million years ago.*

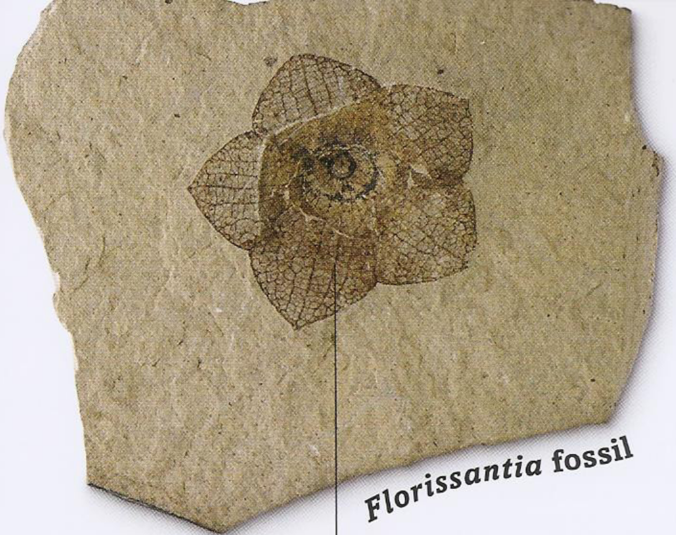
Plane tree leaf fossil

Many fossilized leaves *are like living ones.*

Bee fossil

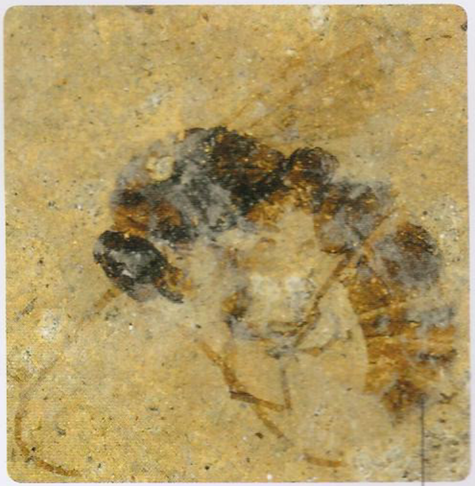
About 20 million years ago*, this bee was sipping nectar and carrying pollen just like a modern honeybee.*

During most of the Mesozoic age of dinosaurs there were no colorful, fragrant flowers to attract insects. The plant world was dominated by the green leaves of ferns, palmlike cycads, and conifer trees. The earliest known flowering plants date from about 140 million years ago. Most of their flowers were small and pollinated by the wind, like grass flowers. But by about 100 million years ago many had big, vibrant flowers like those of **early magnolias** and ***Archaeanthus***, and by the time the dinosaurs were wiped out, the world had



***Florissantia* fossil**

Formed 49 million years ago, *this fossil has traces of structures that produced sugary nectar.*



Giant winged ant fossil

Every detail of this queen ant *has been preserved in a fossil that is about 47 million years old.*

The crushed exoskeleton *of this 50-million-year-old beetle still glitters as it did when alive.*

Jewel beetle fossil

Still around today, **jewel beetles** date back to about 150 million years ago.

Archaeanthus

These bright petals *would have attracted early pollen-feeding beetles.*

Water chestnut

The spiky fruit *of water chestnuts provided food for early Stone Age people.*

been transformed. The following Cenozoic Era saw an increase in plants with showy, nectar-bearing, and possibly fragrant flowers like those of ***Florissantia***. They evolved alongside nectar-feeding insects, including **bees** and **butterflies**. These insects transferred pollen from flower to flower much more efficiently than the wind, enabling the plants to set seed more easily. This meant that the Cenozoic—the age of mammals—was probably far more colorful than all previous ages, and buzzing with a greater variety of insect life than ever before.

Trapped in amber

Praying mantis

***Looking exactly as it would when alive**, this mantis seems to have caught an ant before it was trapped.*

***The big claws** of this scorpion are just like those of modern scorpions, which use them to seize prey.*

Bird

***The claws of a baby bird** are visible in this piece of amber; the bird lived 100 million years ago, during the age of giant dinosaurs.*

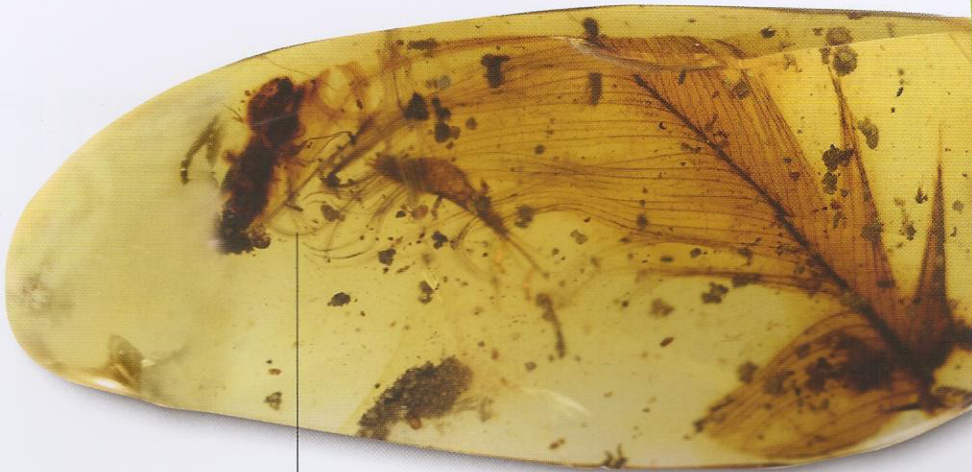
The **oldest** known animals trapped in amber died **230 million** years ago.

Most of our knowledge of prehistoric life comes from fossils—the remains or traces of animals, plants, and other living things that have turned to stone. Usually, only the toughest materials such as bones get fossilized this way, and all the softer tissues are lost.

But one natural process retains every detail of even the smallest animals—preservation in amber. A glasslike, golden-yellow material, amber is the hardened form of sticky resin that oozes from wounds in the bark of trees like pines. Any insect that lands on it may get stuck,

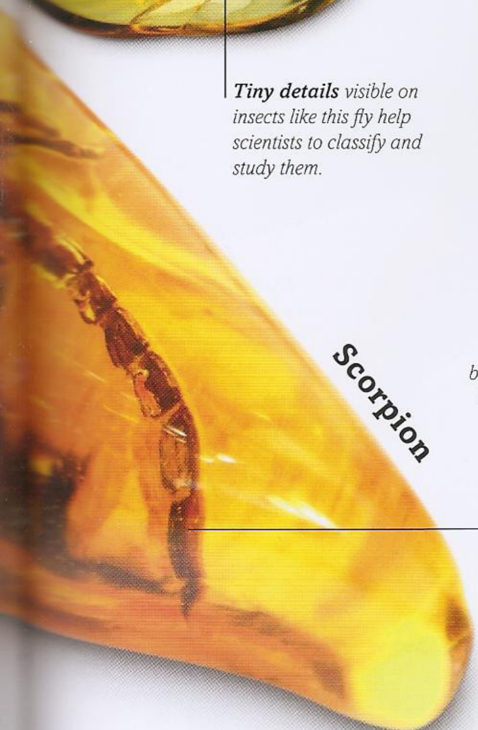
Fly

Tiny details *visible on insects like this fly help scientists to classify and study them.*



Feather

Some feathers *sealed in amber belonged to long-extinct dinosaurs, but were just like those of modern birds.*



Scorpion

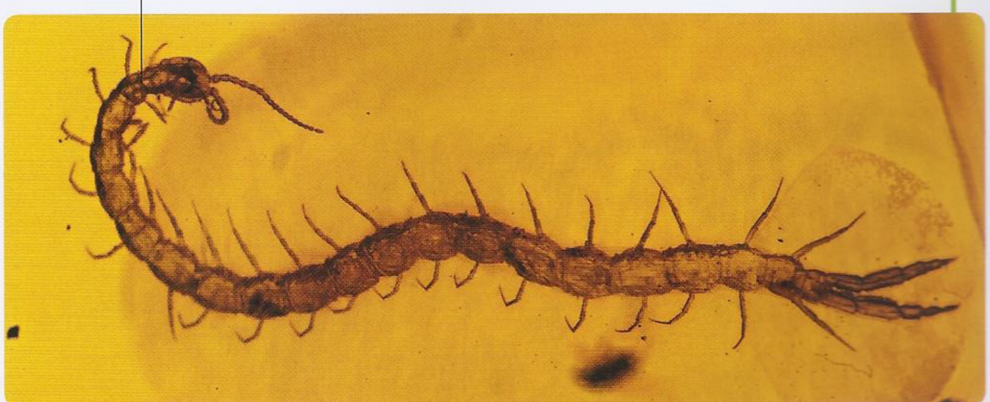
This prehistoric scorpion *probably had a stinger in its tail.*

Lizard

In an attempt to get out of its sticky trap, *this lizard had broken off its tail, just like modern lizards do when trying to escape.*

Spider

The spider *is preserved in resin that is 40–60 million years old.*



Centipede

Although at least 15 million years old, *this centipede is perfect in every detail.*

trapped, and covered by more resin, which kills it. This resin slowly becomes solid, and over millions of years turns into glassy amber, with the insect sealed inside it. Many kinds of small creatures have been found preserved in amber, including insects, **spiders**, **centipedes**, frogs, and even small **birds**. Some of these animals were trapped so long ago that they would have lived alongside the giant dinosaurs. But most amber is more recent, dating from about 44 million years ago, early in the age of mammals.

The first mammals

Fruitafossor *was a squirrel-sized burrowing animal.*

This insect-eater *may have used its strong front limbs to break into termite nests.*

This earliest known pouched mammal *lived 125 million years ago in what is now China.*

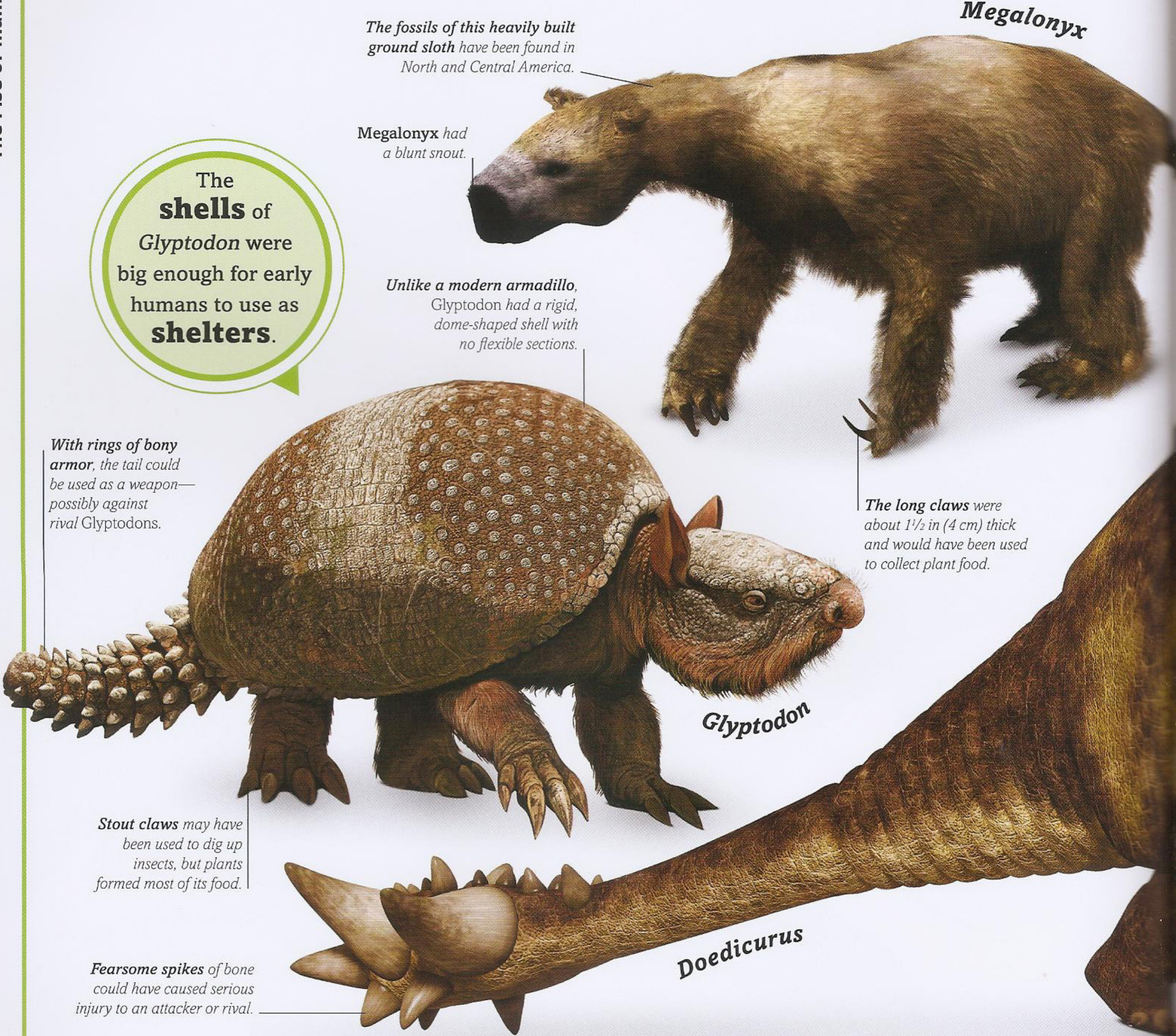
The long back legs *of this insect-eating mammal were adapted for hopping like a rabbit.*

The short limbs *of* Eozostrodon *suited life in burrows, where it hid away from predatory dinosaurs during the day.*

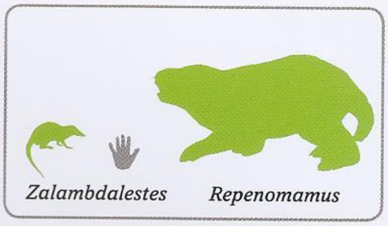
The earliest mammals appeared in the late Triassic Period, about 205 million years ago. Over the next 140 million years mammals lived in the shadow of their dinosaur neighbors. They were small, probably nocturnal creatures that spent most of their time hiding in dense undergrowth, or even underground, preying on insects and small animals. The largest of these secretive creatures, ***Repenomamus***, was no bigger than a badger. The earliest mammals—animals like ***Morganucodon*** and ***Eozostrodon***—would have laid eggs like their

Giant sloths and armadillos

The **shells** of *Glyptodon* were big enough for early humans to use as **shelters**.



While the giant dinosaurs were still alive, mammals were a small part of the wildlife. But the mammals that survived into the new era inherited a world with very few big animals, and over time their descendants started taking over the role themselves. Some of the most primitive mammals to achieve great size were the xenarthrans—the anteaters, the sloths, and the armadillos and their relatives. Like their modern counterparts, they lived in South America, although some spread to North America when the two continents eventually became



Megazostrodon

Resembling a modern shrew, *Megazostrodon probably preyed on worms and other invertebrates.*

Morganucodon

Morganucodon *was only 4 in (10 cm) long, and probably hunted at night for insects such as beetles.*

Repenomamus

Repenomamus *had sharp teeth and powerful jaws.*

One **fossil** of *Repenomamus* shows the remains of a baby dinosaur in its stomach.

The short, strong legs *enabled* Repenomamus *to forage for food across a wide area.*

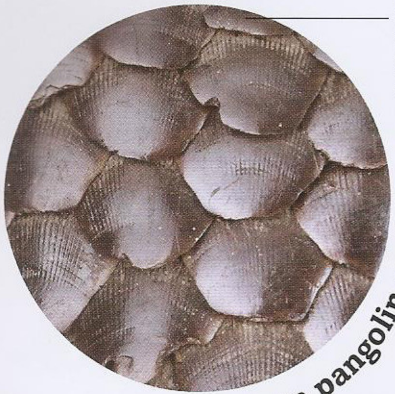
reptile ancestors and like the modern platypus. Living mammals that breed like this are called monotremes. But later in the Mesozoic Era, animals like ***Sinodelphys*** started bearing live young in the same way as modern kangaroos and other pouched mammals (marsupials).

Placental mammals, which bear well-developed babies, appeared a little later, about 90 million years ago. All three types of mammal survived the mass extinction that ended the Mesozoic Era, and the survivors became the ancestors of all modern mammals.

connected. Over the course of 66 million years until the end of the last ice age, they gave rise to some spectacular animals. These included the enormous, armadillolike plant-eater ***Glyptodon*** and the heavily armed ***Doedicurus***, which were both protected from predators by bony armor.

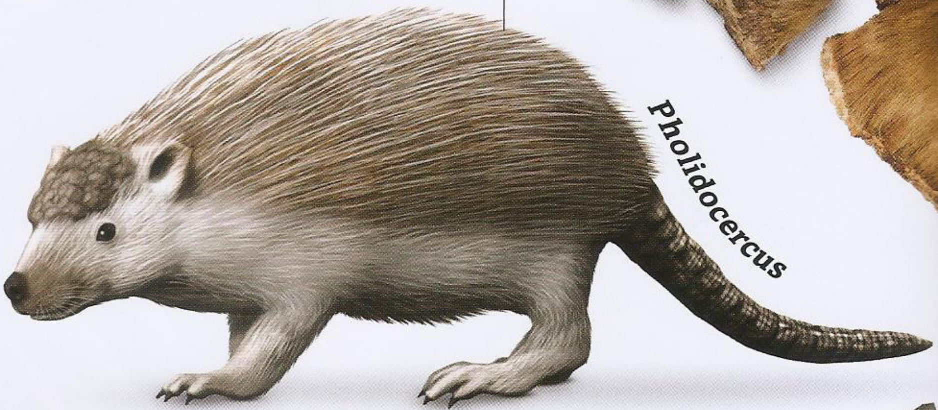
Biggest of all was the giant ground sloth ***Megatherium***, a specialized leaf-eater that grew to the size of an Indian elephant. Able to rear up on its hind legs to reach high into the trees, it gathered food with its long front claws and mobile lips.

Body cover



Modern pangolin scales

***The scales** of pangolins and their extinct ancestors are made of keratin—the same material that forms hair.*



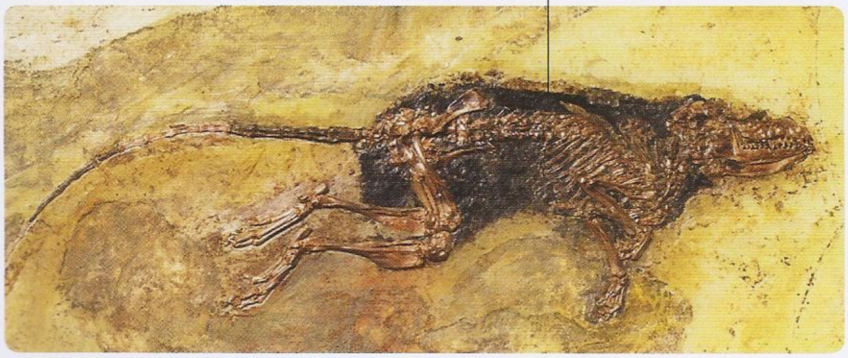
Pholidocercus

***The stiff, sharp spines** of this insect-eating mammal helped protect it from predators.*

Doedicurus spiked tail

***An armored relative** of modern armadillos, Doedicurus was also equipped with a defensive tail club.*

Macrocranion *fossils found in the 47-million-year-old rocks of the Messel Pit in Germany show evidence of fur.*



***Macrocranion* fossil**

Echidna spines

***Each spine** is a modified hair, with a spongy core and a very sharp tip.*

A lot of the energy that a mammal gets from its food is turned into heat that keeps its body warm. The less heat it loses through its skin, the less it has to eat, so most mammals are covered with hair or fur that acts as insulation. Other animals like bumblebees have furry bodies, but the fibers have a different structure. Only mammals have true hair, and it evolved early in their ancestry, probably more than 250 million years ago. Some of the earliest physical evidence is seen in 125-million-year-old fossils of ***Eomaia***, which show traces of fur

Mylodon hide

The fur *of this ground sloth is so well preserved that it was once thought the animal might not be extinct.*

Palaeochiropteryx

Bats *such as the 47-million-year-old* Palaeochiropteryx *flew on wings of naked, stretched skin.*

Armor fossil fragments

Glyptodon

The tough armor *of* Glyptodon *was made up of hundreds of bony plates called osteoderms.*

Glyptodon *had powerful claws for climbing and digging.*

Eomaia

The fossils of Eomaia *are some of the earliest to be found with traces of fur.*

Glyptodon was about the **size** and **shape** of a Volkswagen **Beetle**.

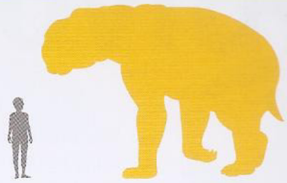
around the bones. Actual fur has been found on fragments of ***Mylodon*** hide preserved for more than 12,000 years in cold, dry South American caves. Hair can be modified to form prickly spines for defense, as in echidnas and the hedgehoglike ***Pholidocercus***, which lived 47 million years ago. Other fossils preserve the armor of armadillolike animals such as ***Glyptodon*** and ***Doedicurus***, and the fossils of some extinct mammals show traces of tough, overlapping scales like those of a modern pangolin.

Mega-marsupials

Many early mammals were marsupials—mammals whose half-formed young live in the mother's pouch until fully developed. Marsupials were thriving in South America and Australia, which had once been part of the same continent, about 100 million years ago. Some, like the fearsome saber-toothed ***Thylacosmilus*** and the hyenalike ***Borhyaena***, continued to live in South America alongside placental mammals (mammals that give birth to well-developed young). But there were no placental mammals in Australia, so marsupials

LARGEST MARSUPIAL

The giant wombat *Diprotodon* was the largest marsupial that ever lived. Up to 10 ft (3 m) long, it stood almost 7 ft (2.1 m) tall. It had enormous front teeth that it used to rip the leaves off bushes and trees, and big cheek teeth for mashing the leaves to a pulp.



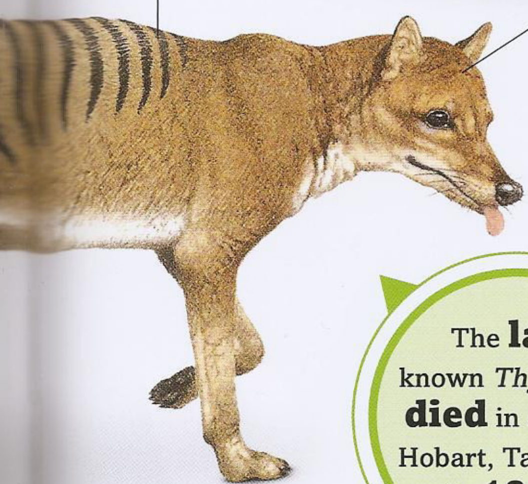
Diprotodon

This enormous marsupial *was a relative of the modern wombat and koala, and like them, it ate plants.*

About 10 ft (3 m) tall*, the biggest species of* Procoptodon *was the largest-known kangaroo; it lived until about 50,000 years ago.*

Procoptodon

Like modern kangaroos*, the mother carried her baby in a pouch until it could feed itself.*



Stripes may have acted as camouflage *in wooded habitats, concealing the animal from its prey.*

The skull and jaws *of* Thylacinus *were very similar to those of a wolf.*

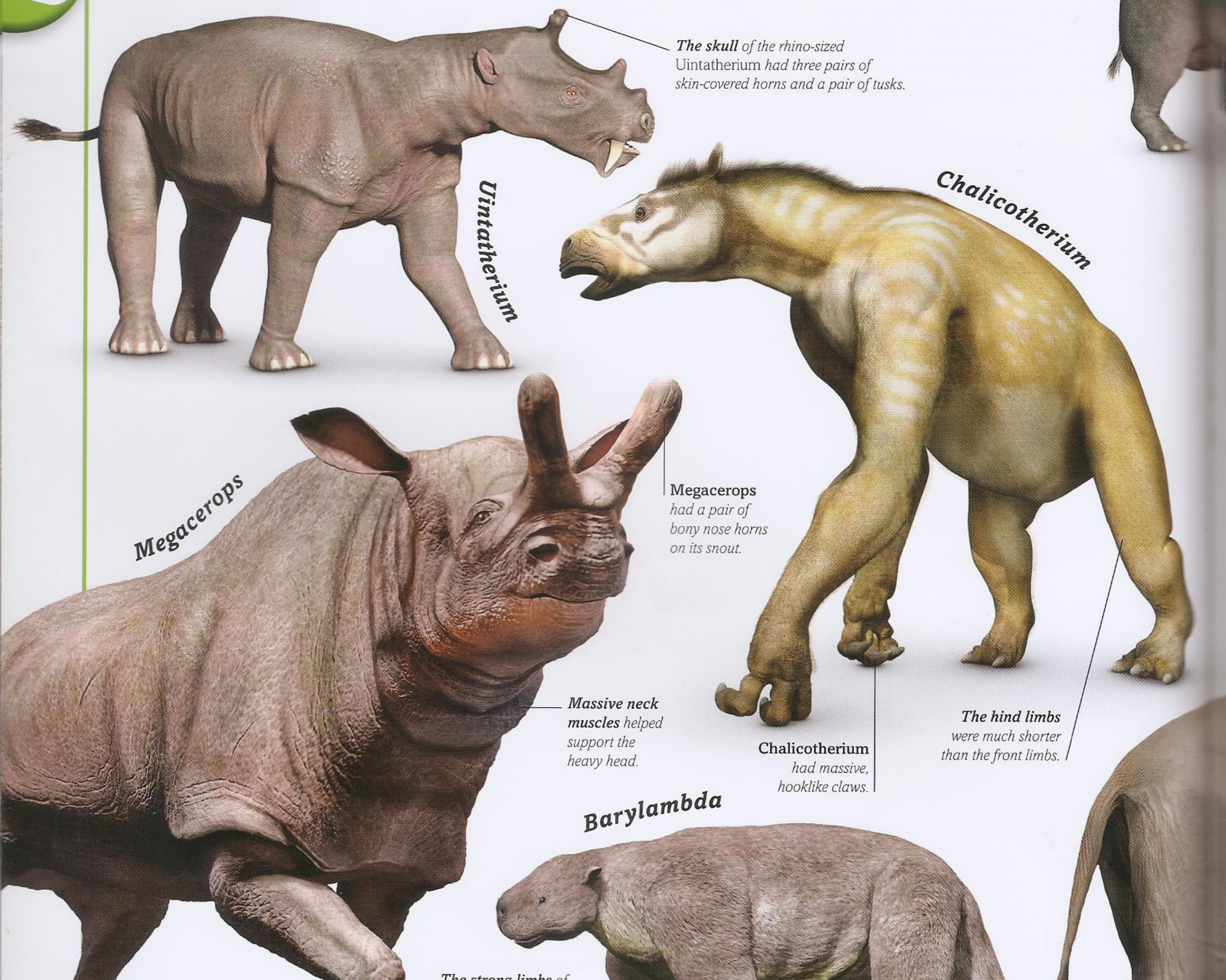
The **last** known *Thylacinus* **died** in a zoo in Hobart, Tasmania, in **1936**.

The heavily built **Borhyaena** *lived about 16 million years ago in Argentina.*

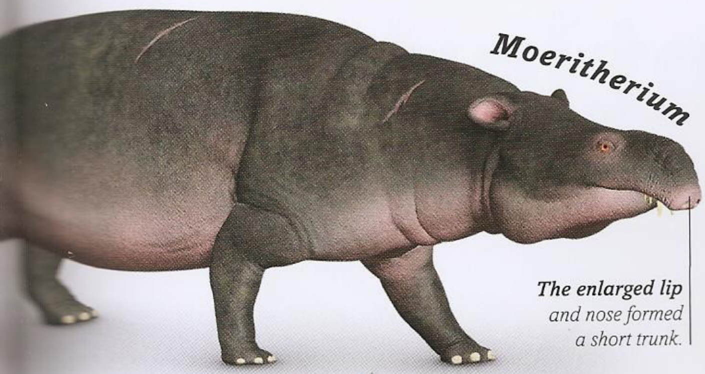
Borhyaena

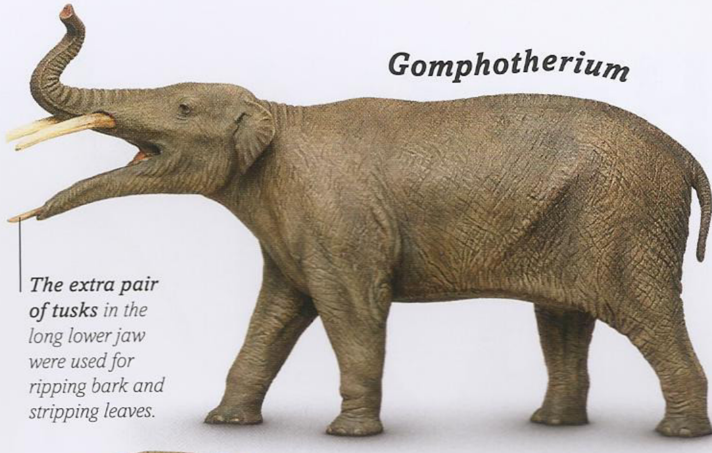
evolved to take their place. They included ancestral koalas; the plant-eating, tapirlike ***Palorchestes***; and the predatory marsupial lion ***Thylacoleo***. During the ice ages, some of these animals grew to huge sizes, like the giant kangaroo ***Procoptodon*** and the hippopotamus-sized wombat ***Diprotodon***. Most of these ice-age marsupials had become extinct by about 30,000 years ago, probably because climate change had created a drier climate, but ***Thylacinus***, also known as the Tasmanian wolf, survived into the early 20th century.

Giant herbivores

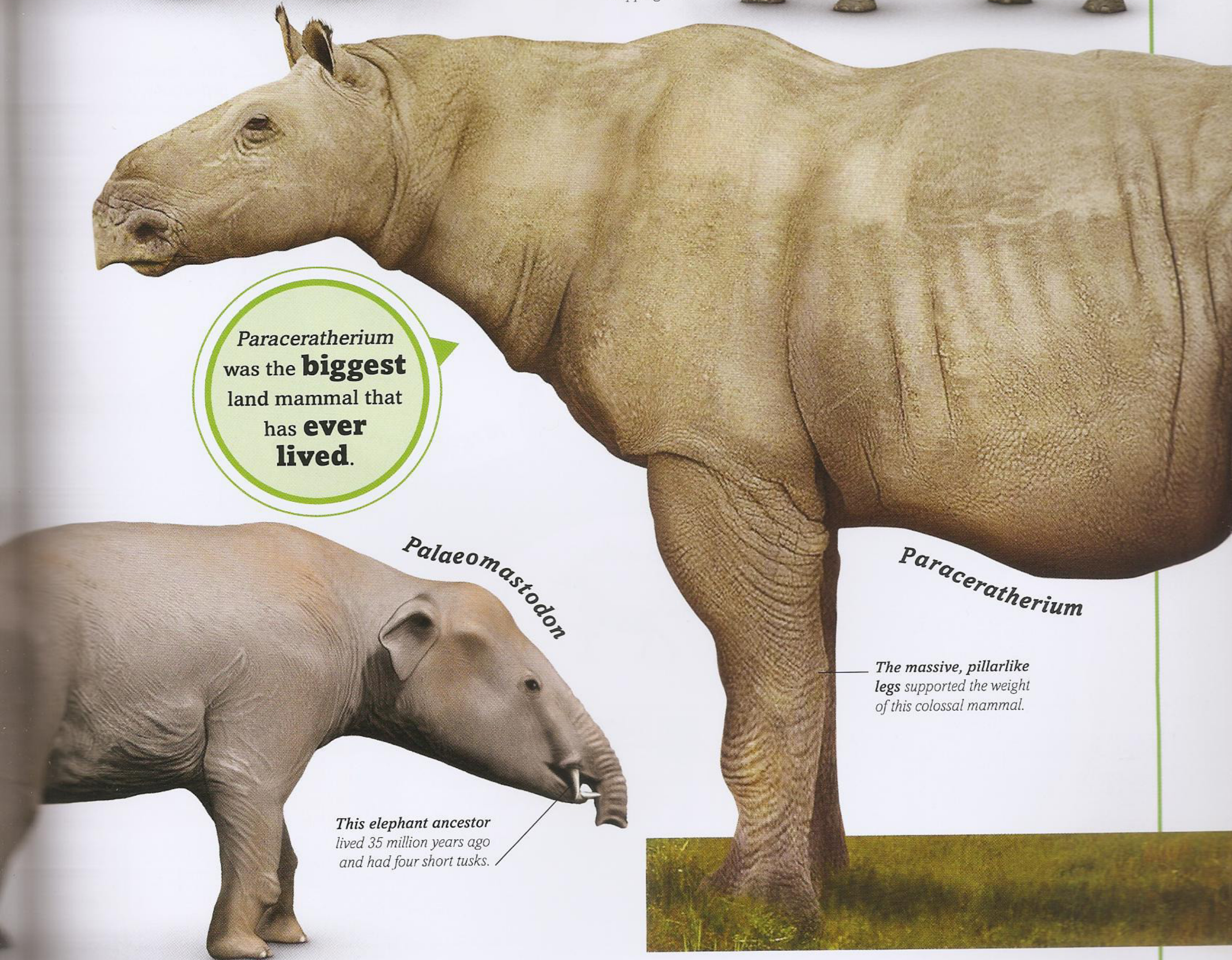


After the disappearance of the giant dinosaurs about 66 million years ago, most mammals were still pretty small. But over time, new types evolved and replaced the huge plant-eaters that had vanished from the Earth. Fossils dating from after 60 million years ago show that the world's forests and plains were becoming populated by a range of spectacular herbivores. These eventually included the early elephant ***Gomphotherium*** and the odd-looking ***Chalicotherium***, with its long claws that forced it to walk on its knuckles. Some of the biggest of





Paraceratherium was the **biggest** land mammal that has **ever lived**.



these animals are known as megaherbivores—***Paraceratherium*** was 18 ft (5.5 m) tall and could reach high into the treetops like a giraffe. Despite their immense size, the megaherbivores were preyed upon by heavily armed hunters like the saber-toothed cats. Most of these plant-eating giants have now vanished—they flourished right up until the end of the most recent ice age about 11,500 years ago—but a few megaherbivores, like the elephants, rhinos, hippopotamuses, and giraffes, still survive in some parts of the world.

Horns and antlers

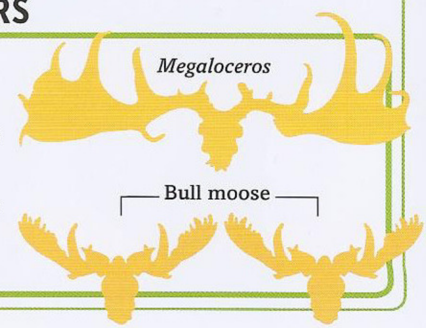
The bony knobs on the nose of Megacerops *were bigger in males and were probably used for fighting rivals.*

These massive paired horns *were extensions of the bony skull.*

The antlers of males *broke off at this point every year after the fall mating season and regrew in spring.*

SUPERSIZED ANTLERS

At up to 10 ft (3 m) long, and with huge antlers, a bull moose is the largest living deer. *Megaloceros* was about the same size, but its antlers were twice the span and weighed up to 88 lb (40 kg). These antlers would have grown from nothing to full size in about 5 months, making them the fastest-growing animal organ.



Many of the big plant-eating mammals that replaced the giant dinosaurs had spectacular horns and other structures on their heads. Some, like the long, sharp horns of ***Pelorovis***, may have helped the animals defend themselves against hungry predators. But others were definitely for fighting with their own kind or simply showing off. Among many modern mammals, possessing the biggest set of horns is a mark of high status, ensuring breeding success. There is no reason why extinct mammals would be any different. Since

the animals with the most impressive headgear were more likely to breed, the horns got bigger over time, resulting in huge structures like the paired bony horns of ***Arsinoitherium*** and the massive single horn of ***Elasmotherium***. But the biggest horns of all belonged to the giant deer ***Megaloceros***. They were antlers—horns that are shed and regrown each year. These antlers could span 12 ft (3.6 m). Only males had them, and they were used to impress and, if necessary, fight rival males trespassing on their breeding territory.

Powerful predators

The giant herbivores that took the place of extinct plant-eating dinosaurs were preyed upon by a variety of big, heavily armed hunters. The earliest of these were doglike animals called creodonts like ***Hyaenodon***, which was probably the fastest predator of its time. But by about 11 million years ago, these animals had been displaced by the true carnivores—the group that now includes cats, dogs, bears, and hyenas. The most fearsome of these hunters—***Barbourofelis*** and the saber-toothed cat ***Smilodon***—had long,

Epicyon

A powerful, heavily built predator, *Epicyon was about 5 ft (1.5 m) long.*

The giant dog *Epicyon* **weighed** as much as a modern **grizzly bear**.

Armed with bone-crushing jaws *that were studded with sharp teeth, Hyaenodon could easily pierce flesh.*

Hyaenodon

Smilodon

Smilodon *would have used its long, saw-edged saber teeth like daggers to stab and kill its prey.*

The front legs *were unusually powerful, and would have been used for grappling big animals to the ground.*

knifelike canine teeth for stabbing their big prey. Other carnivores, such as the massively built short-faced bear ***Arctodus*** and the bone-crushing dog ***Epicyon***, probably relied on brute strength to overcome their prey. But creodonts and carnivores were not the only hunters.

One of the biggest land predators that ever existed was the wolflike ***Andrewsarchus***, which lived about 40 million years ago—a hoofed animal whose closest living relatives are wild pigs.

Mammal teeth

The enormous **saber teeth** of *Smilodon* were up to **11 in** (28 cm) long.

One distinctive feature of a mammal is that it has several types of tooth in its mouth. The basic arrangement is several nipping incisor teeth at the front, four pointed canine teeth adapted for gripping and tearing, and flattened cheek teeth for chewing. This is what humans have. But the teeth of most mammals are modified to suit their diet. The dire wolf, ***Canis dirus***, had longer canines for seizing prey, and some of its cheek teeth were shearing blades for slicing meat. Saber-toothed cats like ***Smilodon*** had huge canine teeth,

***The tusks** were probably used for display and gathering food, like the tusks of modern elephants.*

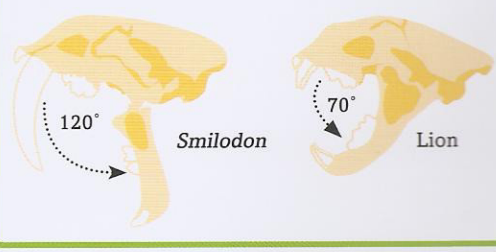
***Huge, flattened cheek teeth** mashed the mammoth's fibrous plant food into a pulp.*

***The cheek teeth** acted like scissor blades to slice through flesh.*

***The cheek teeth** of a woolly rhinoceros were like the teeth of horses, with high crowns for chewing plants.*

WIDE GAPE

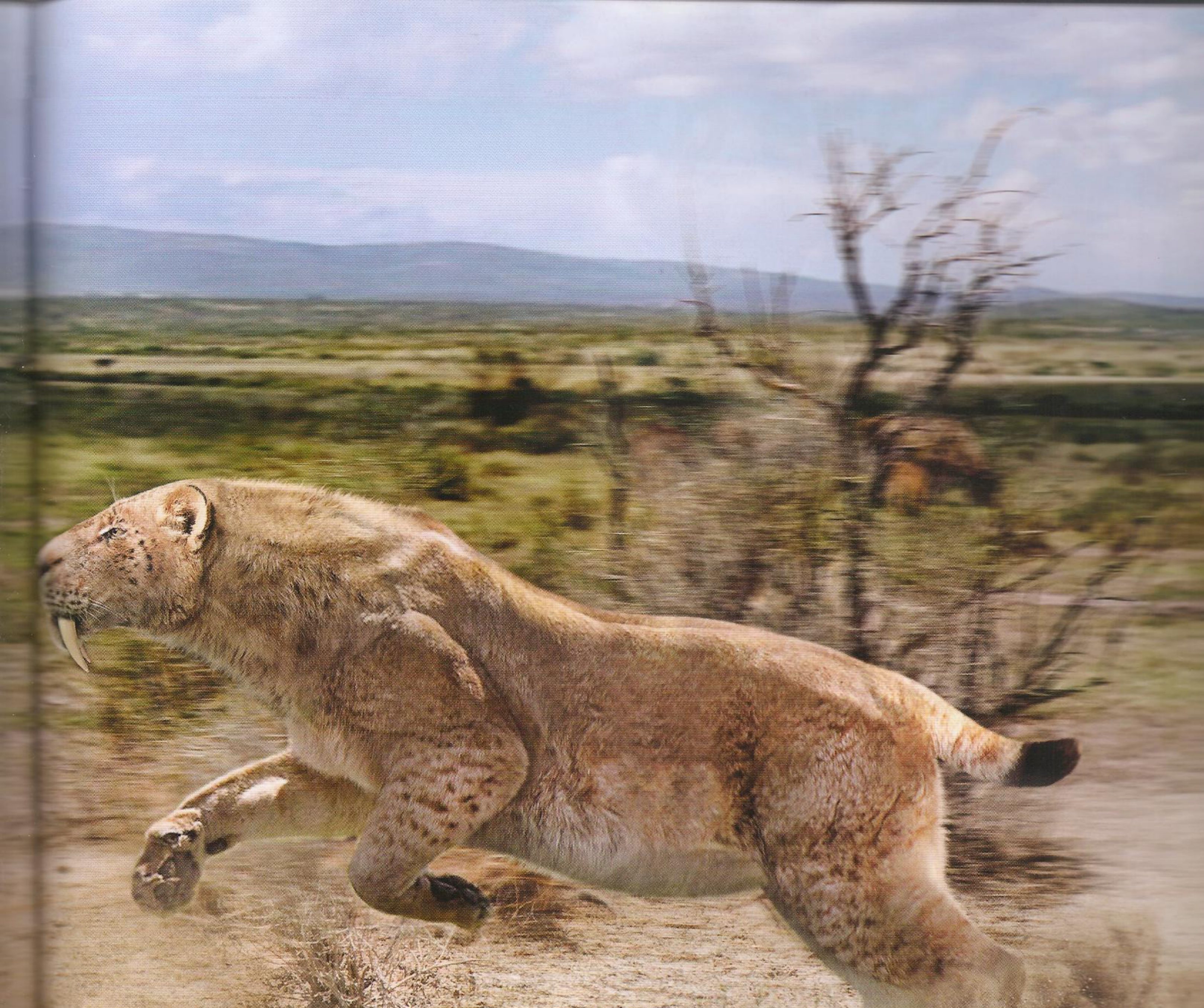
Saber-toothed cats had to open their mouths incredibly wide to attack large prey. A modern lion's lower jaw can rotate by 70°, but *Smilodon* could manage 120°. This helped it use its saber teeth like daggers to bite into its victim's throats.



meat-slicing cheek teeth, and no chewing teeth at all. The plant-eating woolly rhinoceros ***Coelodonta*** had no canines but had large cheek teeth for grinding tough vegetation. A mammoth had giant chewing teeth, and its incisors had become tusks. Marsupials like ***Diprotodon*** had a pair of very long lower incisors that grew forward from the lower jaw to meet the upper front teeth. All these adaptations, and more, have been inherited by modern mammals, ranging from wolves and lions to elephants and kangaroos.

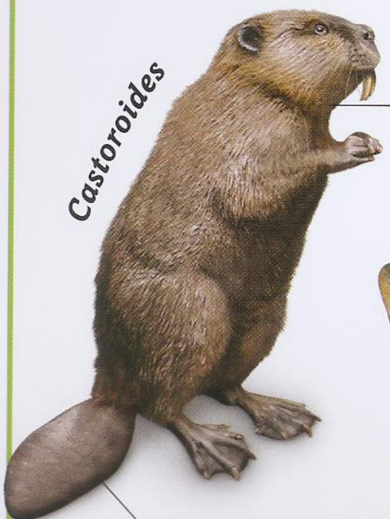
SABER CHARGE

Two hundred years ago, soldiers on horseback charged at enemies while brandishing curved swords called sabers. Twenty thousand years earlier, the big cat *Smilodon* attacked its prey with a pair of huge canine teeth that had the same bladelike form—long, slender, and sharp-edged. *Smilodon* used its saber teeth to bring down formidable prey.



Saber-toothed cats like *Smilodon* lived in an era of giant plant-eating mammals known as megaherbivores. These included many extinct animals, as well as ancestral elephants, rhinos, and bison. Although tempting targets for big predators, these animals were hard to kill because of their size and strength. But *Smilodon* was built for the job, with immensely powerful shoulders and forelimbs, as well as those terrifying teeth. It probably ambushed its prey, leaping onto them and wrestling victims to the ground with its claws. *Smilodon* would then use its long sabers to bite deep into the animal's neck, slicing through major blood vessels with surgical precision. For the victim, it would all be over very quickly.

Ice-age giants



Castoroides

***At up to 7 ft (2.1 m) long**, this huge beaver was the size of a bear.*

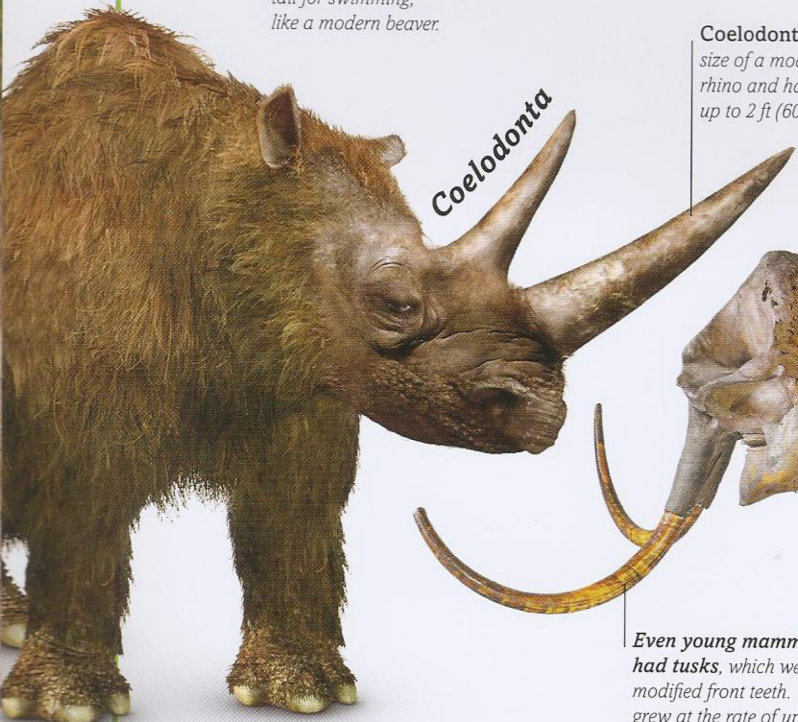
Castoroides *may have had a flattened tail for swimming, like a modern beaver.*

Entire mammoths are regularly **found** buried in frozen ground in Siberia.

Male mammoth

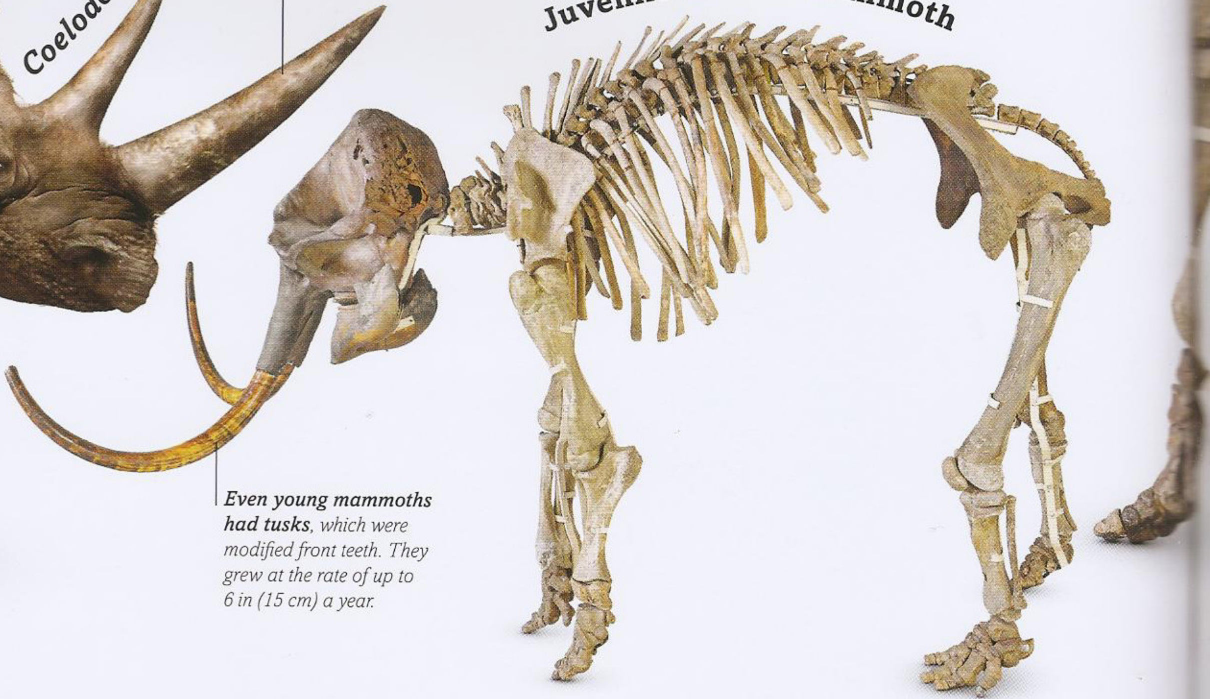
***The high-domed skull** was similar to that of the Asian elephant.*

***The tusks of a male mammoth** could be up to 14 ft (4.2 m) long and grew in a spiral that made the tips point inward and almost touch each other.*



Coelodonta

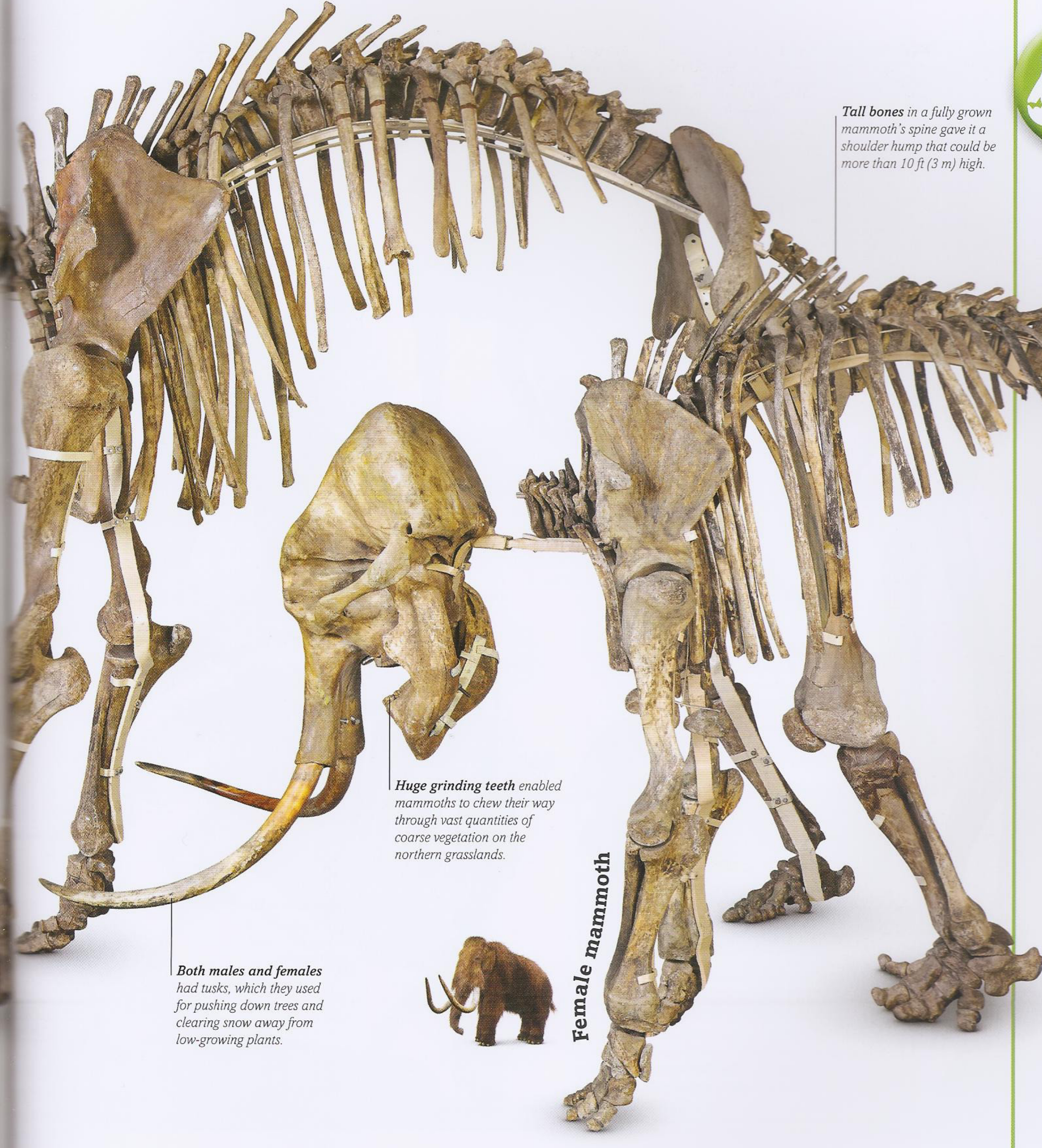
Coelodonta *was the size of a modern white rhino and had two horns up to 2 ft (60 cm) long.*



Juvenile female mammoth

***Even young mammoths had tusks**, which were modified front teeth. They grew at the rate of up to 6 in (15 cm) a year.*

About 2.6 million years ago, the world's climate became cooler triggering a succession of ice ages. During these cold phases, vast ice sheets extended south from the Arctic across much of North America and northern Eurasia. The landscape beyond the ice sheets resembled the snowy, treeless tundra found today in regions like Alaska and Siberia. The southern continents were less affected because they were farther from the pole. During the ice ages, many plant-eating mammals evolved a large body size as an adaptation



Tall bones *in a fully grown mammoth's spine gave it a shoulder hump that could be more than 10 ft (3 m) high.*

Huge grinding teeth *enabled mammoths to chew their way through vast quantities of coarse vegetation on the northern grasslands.*

Both males and females *had tusks, which they used for pushing down trees and clearing snow away from low-growing plants.*

to life in the cold. The **woolly mammoth** and the woolly rhinoceros ***Coelodonta***, for instance, both had thick hair to keep out the cold, and their bulk ensured that they lost body heat less easily than smaller mammals. They lived in the northern tundra and grasslands, but other ice-age mammals, including some types of mammoth, lived farther south where the climate was less harsh, or moved north only during warm periods between the coldest spells. We have been living in one of these warm periods for the last 12,000 years.

One of the biggest ice-age giants was ***Deinotherium***, a huge elephant relative with down-curved tusks in its lower jaw. It appeared about 10 million years ago but became extinct during the ice ages. Another super-sized animal was ***Elasmotherium***, a type of rhinoceros that lived alongside the **woolly mammoth** in the colder parts of northern Europe and Asia. Farther south there were vast forests that provided a habitat for **bison** and other wild cattle, like the aurochs, *Bos primigenius*, an ancestor of domestic cattle. The open

***No horn** has been preserved as a fossil, but ice-age cave paintings indicate that it was very tall.*

Elasmotherium *had huge, flat-topped teeth, ideal for eating a diet of tough, fibrous grass that needed a lot of chewing.*

The name *Deinotherium* means **"terrible beast"** in ancient Greek.

***The tusks** grew from the lower jaw, unlike those of a modern elephant.* Deinotherium *may have used them for digging or to pull down tree branches.*

***The enormous antlers** were about 11 ft (3.5 m) from tip to tip.*

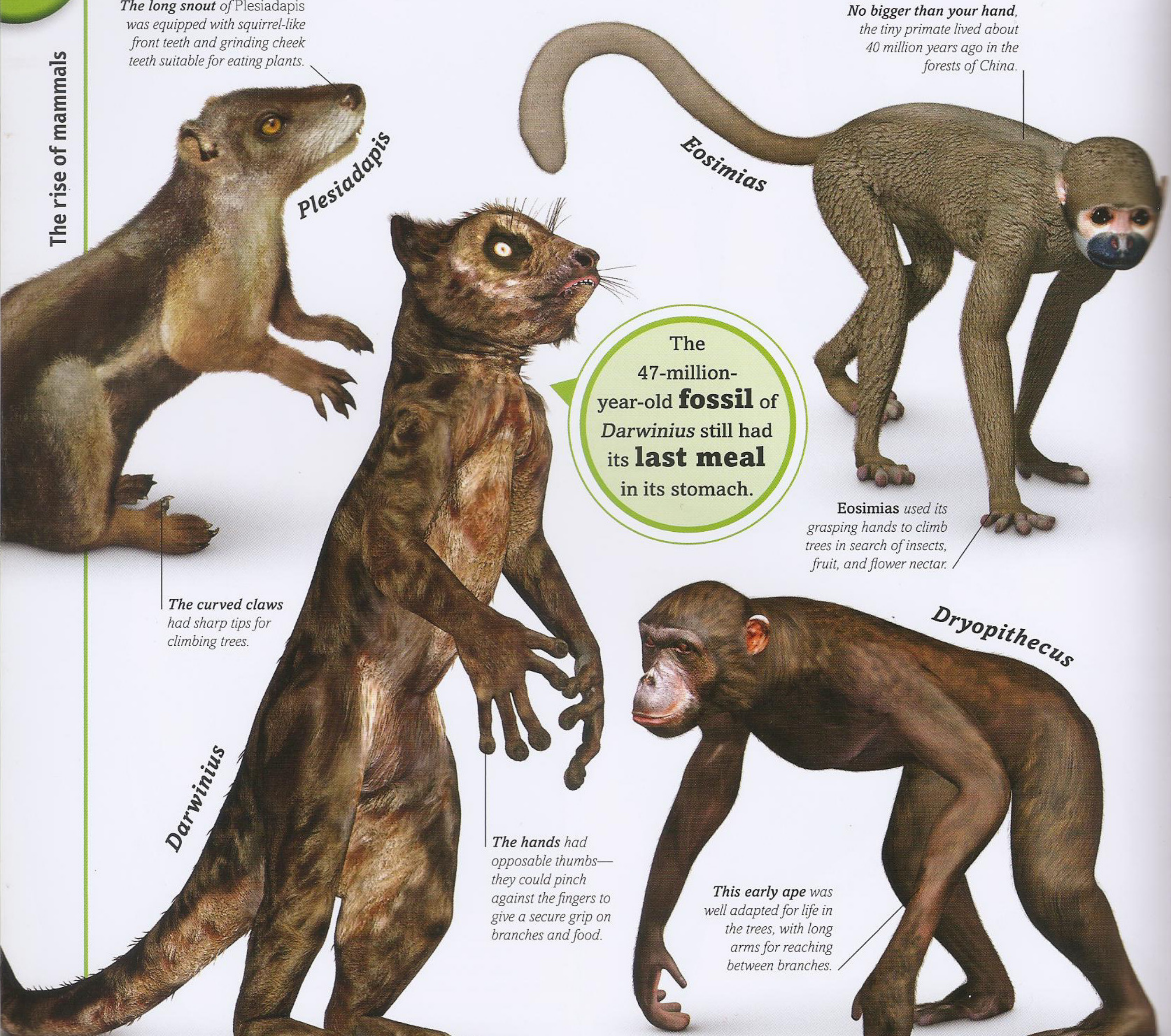
Megaloceros *stood about 7 ft (2.1 m) tall at the shoulders.*

TAR PITS

Many fossils of ice-age mammoths have been found in a group of tar pits near Los Angeles. The animals became trapped in the sticky tar and attracted predators, including saber-toothed cats and ice-age wolves, which also became trapped. Shown above is part of a *Smilodon* skull, blackened by tar.

woodlands of Eurasia were also home to the giant deer ***Megaloceros***. The males had the biggest antlers of all time, which they used to impress females and to spar with rivals. All these animals lived at the same time as early stone-age humans, who would have hunted them for food. Many animals became extinct at the end of the last ice age, about 12,000 years ago. This was partly because of human hunters but also because changing climates eliminated many of their habitats.

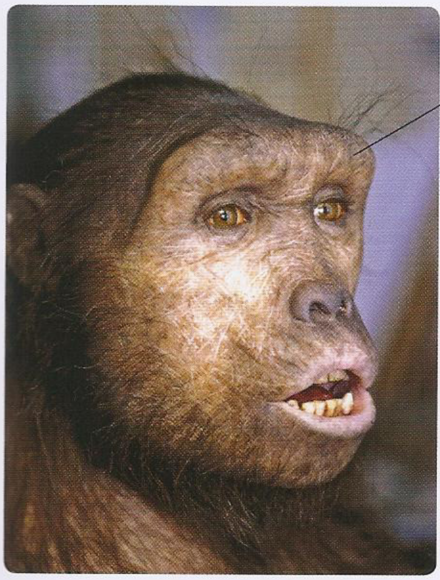
Primates



The 47-million-year-old **fossil** of *Darwinius* still had its **last meal** in its stomach.

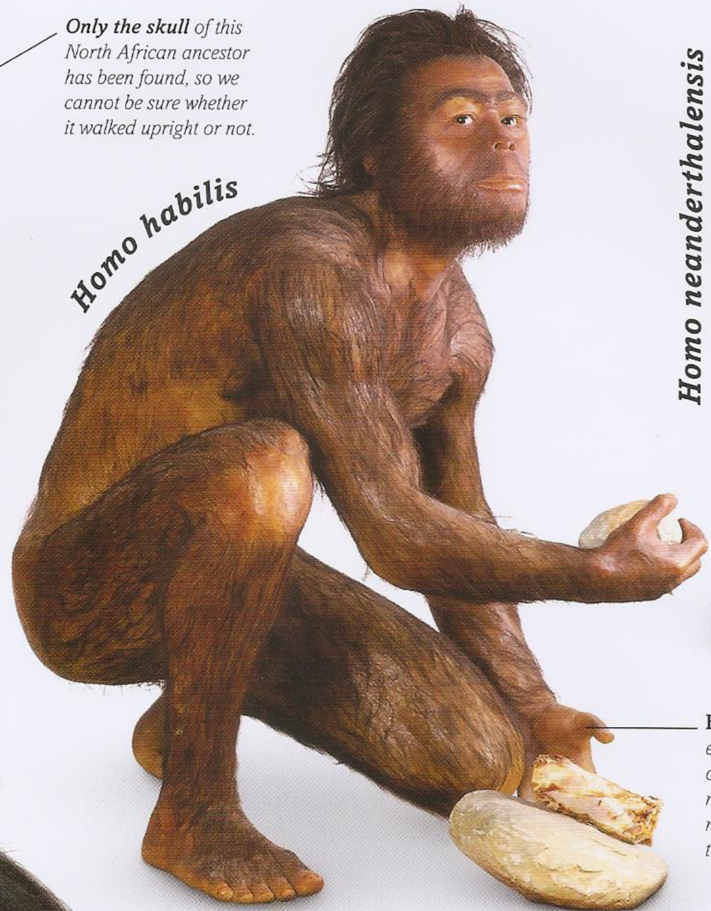
The first primates, such as *Plesiadapis*, appeared about 56 million years ago. They soon split into lemur-type primates, like ***Darwinius***, and early monkeys like ***Eosimias***. The oldest-known apes were alive about 25 million years ago. Their descendants were mostly tree-dwelling animals such as ***Dryopithecus***, which would have walked on all fours when on the ground. However, some later apes adapted to life on the ground by walking upright on their hind legs. They included our own ancestors.

Early humans



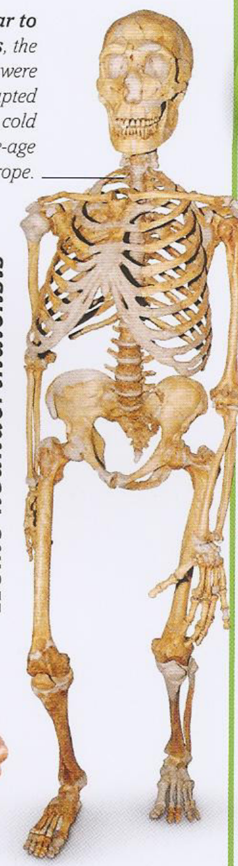
Only the skull of this North African ancestor has been found, so we cannot be sure whether it walked upright or not.

Sahelanthropus



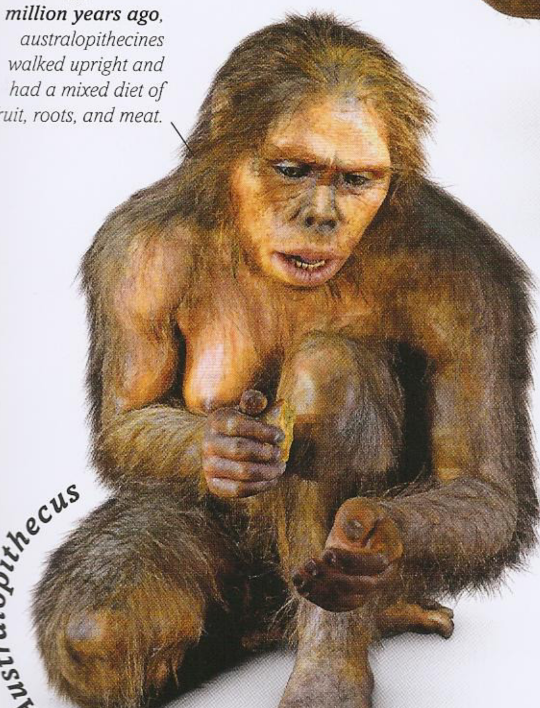
Homo habilis

Homo habilis *was the earliest member of our own genus,* Homo. *Its name means "handy man"—it used its hands to make stone tools.*



Very similar to modern humans*, the neanderthals were sturdy people adapted for life in the cold climate of ice-age Europe.*

Homo neanderthalensis



Living from 4–2 million years ago*, australopithecines walked upright and had a mixed diet of fruit, roots, and meat.*

Australopithecus

BIGGER BRAINS

The key difference between humans and other apes is intelligence. Our ancestors were walking upright for a while before their brains started getting bigger. As their brains grew, their jaws became smaller. The average brain size of the very early *Homo ergaster* was 52 cubic in (850 cubic cm), increasing in *Homo heidelbergensis* to 75 cubic in (1,225 cubic cm), and finally 82 cubic in (1,350 cubic cm) in modern *Homo sapiens*.

1.8 MYA–600,000 YA

Homo ergaster

600,000 YA–250,000 YA

Homo heidelbergensis

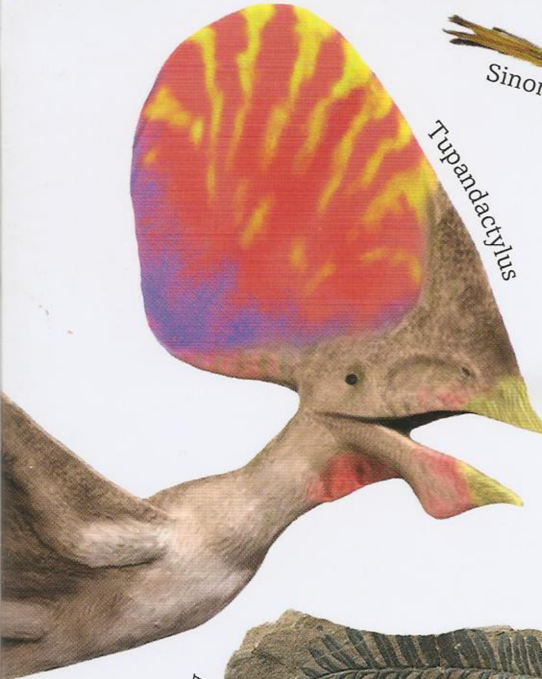
150,000 YA–PRESENT

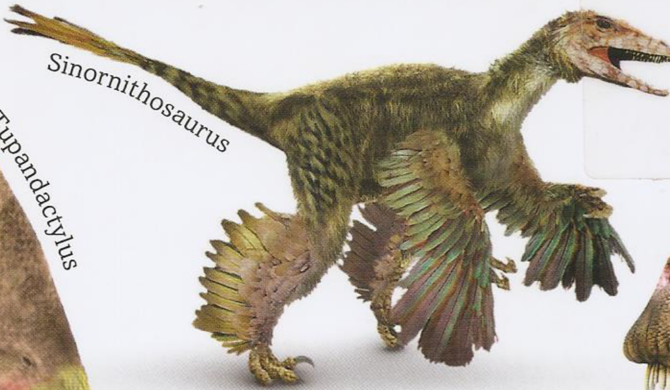
Homo sapiens

The earliest ancestors of humans were very like *Dryopithecus*. *Sahelanthropus* may have been one of the first apes to walk upright. It lived in Africa 7 million years ago and had a brain no larger than that of other apes. By about 3.6 million years ago, ***Australopithecus*** was clearly walking upright: its fossil footprints, similar to our own, have been found in East Africa. Over time, there were many *Australopithecus* species, followed by several *Homo* species. The first modern humans, *Homo sapiens*, evolved in Africa at least 200,000 years ago.

WINDOW TO THE PAST In September 1940, an 18-year-old boy climbed into an unexplored cave at Lascaux, southern France, and discovered scenes of prehistoric wonder—a record of animal life at least 17,000 years old. Decorated with more than 900 images, the cave walls depict herds of galloping wild horses, deer, and prehistoric cattle known as aurochs.

During the last ice age, vast areas of northern Europe were snowy tundra, but in southern France, the landscape was a patchwork of forests and grasslands that supported a wealth of wild animals. They were hunted by people who were just like us, but with the different skills needed to survive at the time. The cave walls show that their abilities extended well beyond survival. The paintings were drawn by people who had studied the living animals and carried the memory of them deep into the cave. They were people with curiosity, imagination, culture, and creativity. In other words, they were among the first to show evidence of the defining feature of modern humanity—civilization.





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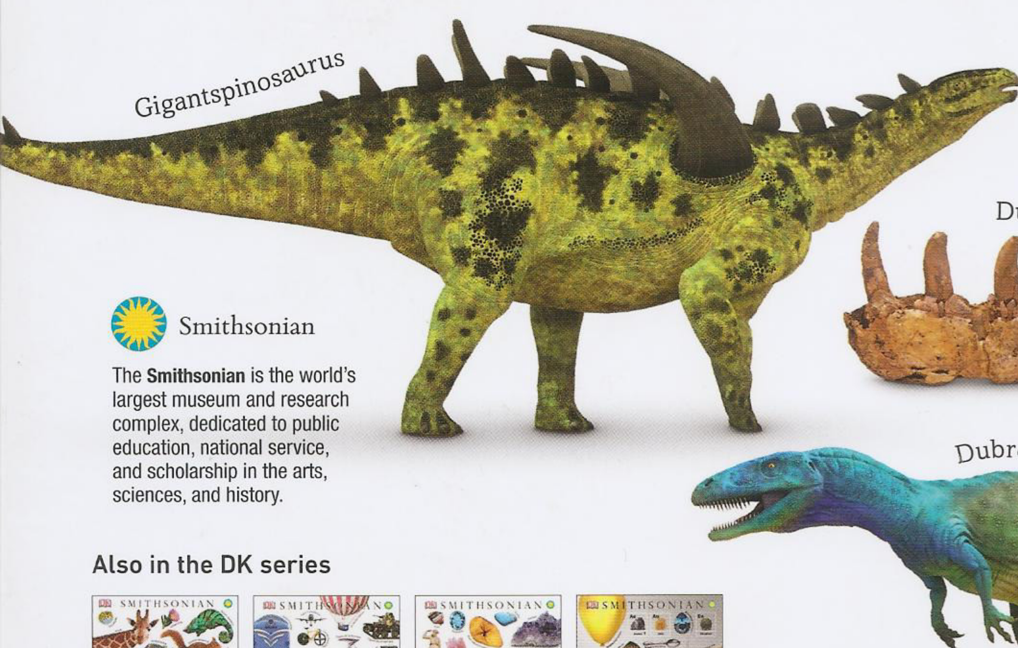

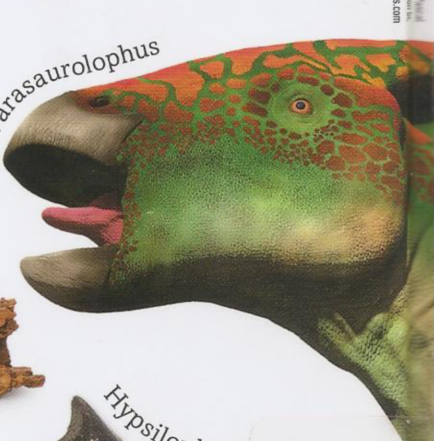

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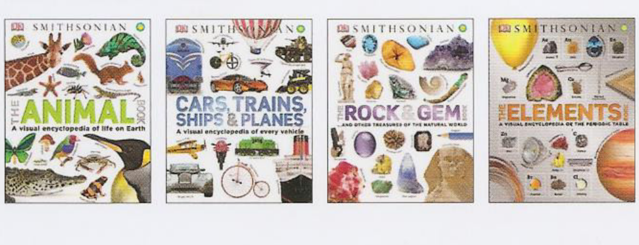

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